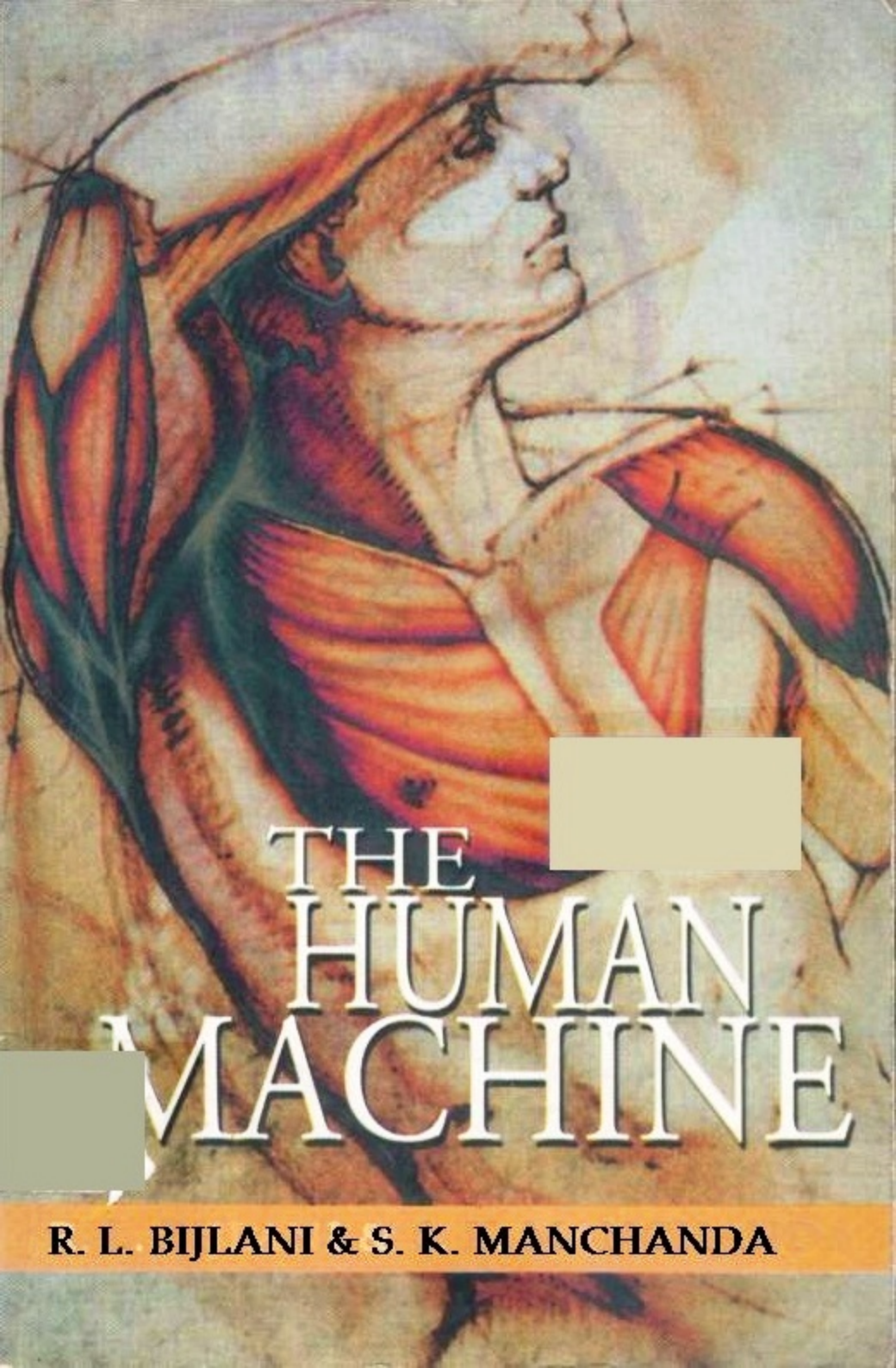

R. L. BIJLANI & S. K. MANCHANDA

Popular Science

THE HUMAN MACHINE

How to Prevent Breakdowns

R. L. Bijlani
S. K. Manchanda

NATIONAL BOOK TRUST, INDIA

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Foreword

Health is a positive state of physical and mental well-being and not merely absence of disease. It would be evident to any person who has studied medicine that human machine is the most ingeniously devised, designed and constructed mechanism that exists in the universe. It has systems of checks and balances and mechanisms which help preserve a state of normality in whatever environment the human body is placed and whatever provocations it is subjected to. As medical knowledge advances, we learn more and more of the mysteries of the structure and metabolic processes which contribute to the state of positive health and defend the body against disease. Intricacies of these mechanisms are hard to understand fully even for a medical student.

Each one of us has our own notions about the functioning of the body, the effect of different kinds of diets and climate on the systems which are based not on any facts but on what we have heard others say. There is acute paucity or near absence of any published material in layman's language which provides correct knowledge about the complex human organism.

Dr Bijlani and Dr Manchanda have done a remarkable job to put across for the layman, knowledge of the human machine in a language that everyone can understand. The simple, cleverly designed diagrams supplement the understanding. I am sure this work has filled a lacuna and every reader will find the experience of going through this book most rewarding.

New Delhi
11 November 1982

H.D. TANDON
Director, AIIMS

Preface to the First Edition

At the outset, we would like to share with the reader the genesis of this book. It was in 1974 that the first ever international meeting on a medical subject was organised by the Union of Physiological Sciences in New Delhi. It naturally evoked immense interest among the journalists. The coverage that the many discussions received in the lay press created a general awareness about physiology as an important medical science. As a sequel to this publicity, we were invited in 1975 by a popular Hindi weekly to contribute some articles on physiological subjects. The articles were highly appreciated, and we felt tempted to add more articles to it to complete the journey through the body and compile them all in the form of a book. However, several obstacles delayed the fulfilment of this seemingly simple dream. We are pleased that at last we have been able to offer you this low-priced volume.

Physiology is not merely a medical discipline. It is the science dealing with the normal function of all living organisms, plants as well as animals. But, in this volume, we shall talk mainly of human physiology, and that too primarily from the point of view of its application to health and disease. Although physiology deals with only normal functions, it has a great role in understanding disease. It is only after the normal function has been learnt that deviations from normal, called disease, can be understood.

Some individuals are pale and weak, and are commonly known as anaemic. Physiology tells us that the normal pinkish hue is due to blood, and that blood is red because

it contains in its red cells a substance called 'haemoglobin'. This indirectly tells us that the pale individual has less haemoglobin—a fact which may be verified by measuring the haemoglobin in her blood. Physiology also tells us that the normal function of haemoglobin is to carry oxygen, and that the harder we work, the more oxygen we need. This explains why the anaemic person is weak. Further, physiology tells us how a normal person's red cells are formed, and how haemoglobin is manufactured. This gives us a rational way of looking for causes of anaemia. For example, one of the substances needed for the synthesis of haemoglobin is iron. Correspondingly, a person deficient in iron has anaemia. If iron deficiency is the cause of anaemia in an individual, giving her iron capsules would correct the problem.

To quote another familiar example, diabetes was considered incurable till about seventy years ago. Two young scientists, Frederick Banting and Charles Best, discovered through physiological studies on dogs, that the substance which prevents normal individuals from passing excessive sugar in urine is insulin, which is manufactured by the pancreas. It was thus concluded that an injection of insulin would cure a diabetic, and it turned out to be so. Besides diabetes, there are many other less common diseases which can be cured by supplying from outside some substance normally made by the body itself. Here we are employing no 'medicine' in the usual sense of the word. We are merely filling a gap in the body which is otherwise normal. This is possible only if we know enough about what is normal.

The examples given above are specific, and many such examples can be provided. But one general fact brings out the relationship between normal and abnormal states of health better than any number of such examples. The normal body has in-built mechanisms for maintaining all vital functions close to a level which we consider normal. When a disease process results in an abnormality, it is the

very same in-built mechanisms which correct the abnormality. For example, in case of fever, the return of the temperature to normal involves the same mechanisms which regulate the body temperature in the healthy state. As a result of these normal corrective mechanisms, majority of the common ailments get cured even if left alone. With their knowledge of physiology, doctors can reassure their patient confidently that everything will eventually be back to normal, and in some cases, they can assist the normal regulatory mechanisms so that recovery from disease is expedited.

The approach throughout the book is to encourage the reader to question, argue and reason. In the process, we also hope to make a humble contribution to creating a 'scientific temper', a dream cherished by Jawahar Lal Nehru. We are glad that our contribution is finally going to materialise during the Nehru Centenary Year. It is difficult to anticipate all the questions that may occur to the reader, and space does not permit answering all those which we can anticipate. But the reader is welcome to write his queries to us.

Finally, it gives us great pleasure in thanking Professor H.D. Tandon, Director, All-India Institute of Medical Sciences till 1984, for writing the foreword to the book. If the book is found useful, the effort that has gone into producing it will be worthwhile.

R.L. BIJLANI
29 June 1989 S.K. MANCHANDA

Preface to the Current Edition

It is with a sense of profound grief that I would like to share with the readers the sad demise of Dr S.K. Manchanda, my collaborator in this project, and also the teacher from whom I got my first lessons in physiology. The opportunity provided by the preparation of this revised edition has been used for updating facts and also enlarging the Chapter on the Cell to incorporate some fascinating facts which are better appreciated now. It is hoped that these changes will further enhance the readability and utility of the book.

5 December 1998 R.L. BIJLANI

1

HEALTH AND DISEASE

"Health means body ease. He is a healthy man whose body is free from all disease; he carries on his normal activities without fatigue. Such a man should be able with ease to walk ten to twelve miles a day, and perform ordinary physical labour without getting tired. He can digest ordinary, simple food. His mind and his senses are in a state of harmony and poise. This definition does not include prize fighters and such like. A man with extraordinary physical strength is not necessarily healthy. He has merely developed his musculature, possibly at the expense of something else."

—Mahatma Gandhi

It is the irony of language that the simplest of words express the most profound ideas. Take, for example, words like life, death, love or truth. In spite of volumes having been written on them the mystery surrounding them has in no way diminished. Health and disease are also words in a similar category. The demarcation between a healthy and a sick individual is not as clear cut as it seems. The subsequent chapters in this book deal with human physiology, i.e. they discuss the mode of functioning of different parts of the body in a healthy person. But the dividing line between health and disease being very thin, there would be all too frequent digressions into disease processes.

The terms 'health' and 'disease' often convey something different when used in different contexts. Even medical doctors use these terms from at least three distinct viewpoints. One may hope to do some justice to the complexity of the topic by discussing these viewpoints separately.

The Scientific Viewpoint

A living organism is comparable to a society. Different members of the society have discrete functions. Some of them perform highly specialised duties; others perform tasks that are not so skilled. The work that each individual performs contributes, or at least should contribute, to the survival of the society in some way. Smooth functioning of the society requires that activities of the members be co-ordinated with one another. This co-ordination is achieved largely by the government.

In complex organisms like man, the body is made up of millions of tiny units called 'cells' (Chapter 3). Cells perform functions of varying degrees of specialisation. Clusters of cells performing related functions are grouped together in the form of organs. The cells of the stomach and intestines serve to take nourishment into the body, cells of the lungs take oxygen into the body, cells of the heart and blood vessels help deliver this nourishment and oxygen to individual cells all over, and cells of the kidneys assist in getting rid of waste products from the body. In short, these organs ensure that nourishment and oxygen are continually replenished, and waste products eliminated from the body. The chief requirement of every cell is that its interior and immediate surroundings should be suitably warm, salty and acidic. The range of temperature, salt concentration, and acidity* that is compatible with life is extremely narrow. In a healthy body, these parameters are maintained within this narrow range by regulatory mechanisms. For instance, during exercise, the activity in concerned muscles increases. This results in an increase in the demand for oxygen. Increased oxygen consumption is accompanied by increased carbon dioxide and heat production in the muscles. If the blood flow that carries oxygen to the muscles were to stay constant, soon there

* Blood and body fluids are slightly alkaline (or less acidic) compared to water. The degree of acidity is regulated within very narrow limits.

would be a dangerous rise in temperature and acidity (due to carbon dioxide) and fall in oxygen concentration. But, what actually happens is that only a slight fall in oxygen or rise in carbon dioxide concentration triggers an opening up of blood vessels supplying the muscles. Thus the blood flow increases, and the essential features of the internal environment of the body (acidity, temperature, etc.) are maintained. Just the opposite type of activity achieves the same result when the exercise stops, thereby decreasing the demand on oxygen. There are also regulatory mechanisms originating in the brain and endocrine organs. For instance, in the above example of exercise, the brain and endocrines bring about some opening up of blood vessels in muscles even before the exercise actually begins. The very thought of exercise is enough to trigger the change in blood flow to the muscles.

The above example is just one of the large number of regulatory mechanisms which are mobilised to keep the body in good functioning order. In other words, the cells of the body are provided a fairly constant internal environment, or homeostatic condition. Derangement of homeostatic mechanisms is the fundamental basis of disease. Various forms of stress invoke the homeostatic mechanisms. So long as the intensity of the stress is within the compensatory powers of the homeostatic mechanisms, the person is healthy. When the challenge stretches the compensatory mechanisms so much as to exceed their capacity, they break down, resulting in disease. An additional set of mechanisms (e.g. the immune mechanisms) might then come into play to restore health. To put it somewhat differently, health and disease are a question of balance between challenge and response (Fig. 1). If the challenge is overwhelming, even a 'very healthy' person may fall sick; on the other hand, a challenge which can normally be handled quite adequately by most individuals, might overwhelm a 'less healthy' person, and make him sick. Thus, there is no strict dividing line between health and disease.

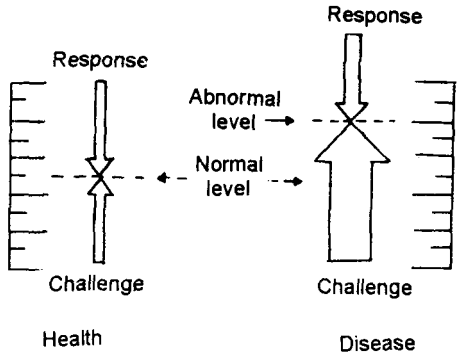

Fig.1: Health and disease are a matter of balance between challenge and response.

There is a continuous spectrum of health, which can proceed to disease under the impact of a threshold challenge (Fig. 2). An example will clarify this discussion further.

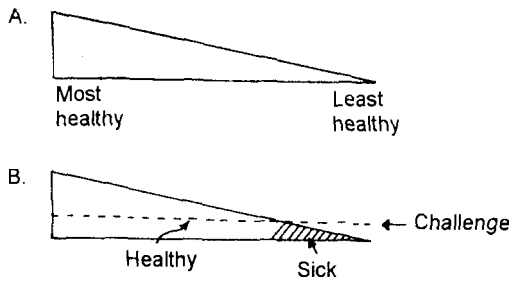

Fig.2: There is no strict dividing line between health and disease. There is a continuous spectrum of health, which can proceed to disease under the impact of a strong enough challenge.

Diabetes Mellitus

The food that we eat has considerable quantities of carbohydrates. On digestion, carbohydrates yield glucose and related substances. When the body gets loaded with glucose, the pancreas (an endocrine gland) responds by secreting insulin, which helps the body in utilising glucose. The

pancreas continues to do this job untiringly, and with precision, for years. As a person gets older, the capacity of the pancreas to respond by releasing insulin diminishes. This does not happen to the same extent in all 'healthy' individuals. If the glucose load during meals in an elderly individual regularly exceeds the residual functional capacity of his pancreas, he will develop manifestations of a relative deficiency of insulin, which is called 'diabetes'. Thus diabetes is basically a balance between the glucose challenge and the insulin response. Many diabetics can re-enter the 'healthy' category by altering the character of their diet so that the glucose load is reduced and is spread over a longer time. Further, many individuals who habitually consume a low glucose-challenge diet, continue to be in the 'healthy' category even though their pancreatic capacity declines to a level which would have forced some others into the 'diabetic' category.

This is the viewpoint that will be repeatedly illustrated by the subsequent chapters dealing with various organs and functions of the human body. But doctors in the clinic have to adopt also another approach to health and disease, which may be called the 'clinical viewpoint'.

The Clinical Viewpoint

Clinicians, or doctors, are also scientists. But their viewpoint is sometimes at variance with the strictly scientific view because the nature of their work requires combining science with some art, empiricism and compromise.

If all the known clinical examinations and laboratory tests were done on an individual, and found within normal limits, there is still a possibility that the individual might have a disease which cannot be detected by any of the tests so far available to medical science. In practice, however, the number of tests performed is limited due to constraints of time, money and convenience. Therefore, the chances of a disease escaping detection are indeed very real, and the disease so missed may be as serious as the

cancer of the stomach. That is why, when asked to certify the health status of an individual, the doctor is usually contented with routine clinical and laboratory tests, the exact nature of which depends on the facilities available and the requirements of the situation. Even if the findings in all these tests are within normal limits, the scientist within the doctor tells him that the subject may not necessarily by healthy, and therefore, he gives him the technically safe certificate, N.A.D., which stands for 'no abnormality detected'.

Another dimension to the clinician's vision of health and disease is added by the large number of patients who visit him with many types of complaints, but who, on clinical examination, are found fit, and all relevant laboratory tests are within normal limits. Scientifically, the patient is essentially healthy. But so long as the 'patient' has complaints, he is sick. Such patients, for whose complaints no physical basis can be discovered, are variously described as 'functional', hypochondriac, or loosely, as having a psychological problem. At the other extreme are 'patients' who personify Sydney Smith's words, "I have gout, asthma, and several other maladies but am otherwise very well." They have very real complaints, for which there is an obvious physical basis, but they prefer ignoring their symptoms, and seldom visit a doctor. The clinician's doubts about health and disease may be summed up in the words of Hippocrates (400 B.C.), the father of modern medicine: "You can discover no weight, no form, no calculation to which to refer your judgement of health and sickness. In the medical arts there exists no certainty except in the physician's senses."

The Public Health Viewpoint

One often comes across instances where figures of average life expectancy or infant mortality rate in a community are used as indicators of health. Such considerations are primarily the concern of a doctor engaged in public health

activities. The public health man's perception of health and disease is coloured by the fact that he thinks in terms of groups. There is, nevertheless, a public health definition of health of an individual, provided by the World Health Organisation, i.e. 'health is a state of complete physical, mental and social well-being, and not merely absence of disease or infirmity'. Although very broad in scope, and ideal, one can understand how difficult it is to achieve, maintain, or identify such a state of health. Therefore, in practice, the public health man just keeps this definition in mind as a goal to be striven for. He measures the health of communities not in terms of these ideals, but in terms of criteria, like maternal or infant mortality rates. It has been found by experience that under the impact of public health measures such as immunisation, sanitation, and maternal and child care, health statistics improve, the most sensitive among the figures being maternal and infant mortality rates. Therefore, they are used by the public health man as indicators of health status of a population.

These are some of the criteria of health and disease familiar to doctors. This does not, however, preclude the importance of other viewpoints. Other dimensions of health, such as moral health or spiritual health, are perhaps equally important, and not entirely unrelated to the medical dimension.

2

CELL: THE BASIC UNIT OF LIFE

You might recollect with pleasure one of your childhood days when you got hold of a piece of coloured glass and were trying to see through it almost every object you could lay your hands on. In much the same way, one might guess, Robert Hooke was playing with a microscope which he had invented himself. He was trying to see the magnified version of all sorts of things. One of those things happened to be a thin slice of cork. He saw in it innumerable minute compartments. He called each one of these tiny 'rooms' a cell (Fig. 3). Quite unwittingly, he had witnessed the structural and functional unit of all forms of life—

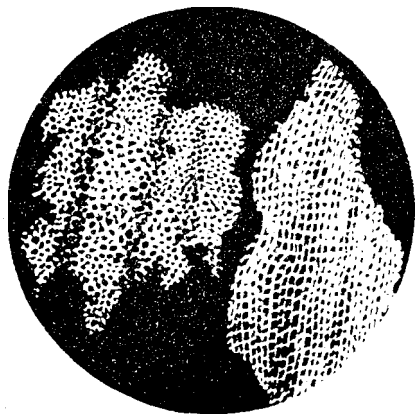

Fig.3: This is how a slice of cork looks under the microscope. Robert Hooke was the first to call each tiny little compartment a 'cell'. (Reprinted with permission from Moon, T.J., Otto, J.H. and Towle, A.: *Modern Biology*, 1963, Fig. 4.1, p. 31. *Courtesy:* Holt Rinehart and Winston, Inc., New York, USA.)

plants as well as animals. That was way back in 1665. However, the concept of a cell being the unit of life took another two centuries to mature, and was first put forth by two German scientists—Mathias Schlieden, a plant scientist, and Theodor Schwann, an animal scientist.

The Cell

If we peel a thin slice of the skin of a fruit or an animal and examine it under the microscope, it will be found to be composed of a large number of units, invisible to the naked eye. Each one of these units is called a 'cell'. Similarly, each of the microscopic units which forms the liver, the brain, the muscles or the leaves, is also called a cell. All these cells have vastly different appearances. The differences are such as to make the cells suitable for the specialised function that they have to perform. For instance, the liver cells have a rich stock of 'reagents' for carrying out diverse

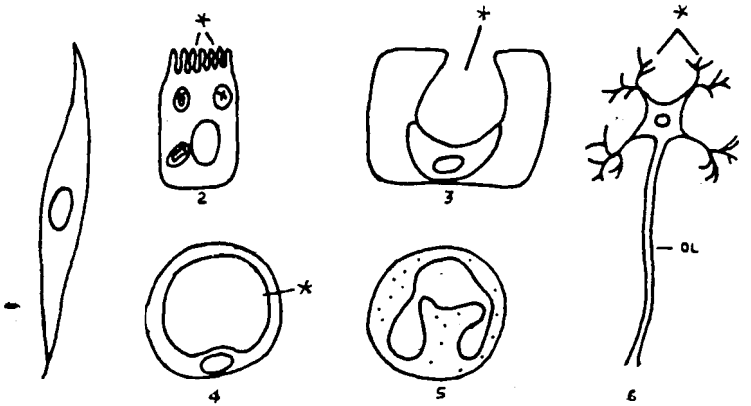

Fig.4: All these diverse looking structures are cells of the human body. They are called cells because they share many common features such as the presence of a nucleus surrounded by cytoplasm: *1.* smooth muscle cell; *2.* intestinal cell,* microvilli; *3.* goblet cell, *mucus; *4.* fat (adipose) cell,* fat vacuole; *5.* neutrophil (a type of white blood cell); *6.* neuron (a nerve cell), *dendrites (processes for receiving messages), **axons (processes for sending messages).

chemical reactions, the brain cells have elongated processes for transmission of messages, while the muscle cells carry long protein filaments arranged in such a way that they can slide into and out of one another, resulting in a change in the length of the cell (Fig.4). In spite of these differences, there are some basic features which are shared by most cells. These common characteristics have led the scientists to call all these diverse structures 'cells'.

In general, cells have a boundary that limits them from other cells, and also from their watery surroundings. The boundary, called 'cell membrane', is a dynamic structure with shifting doors and windows which allow substances to pass into or out of the cell in a selective manner (Fig. 5).

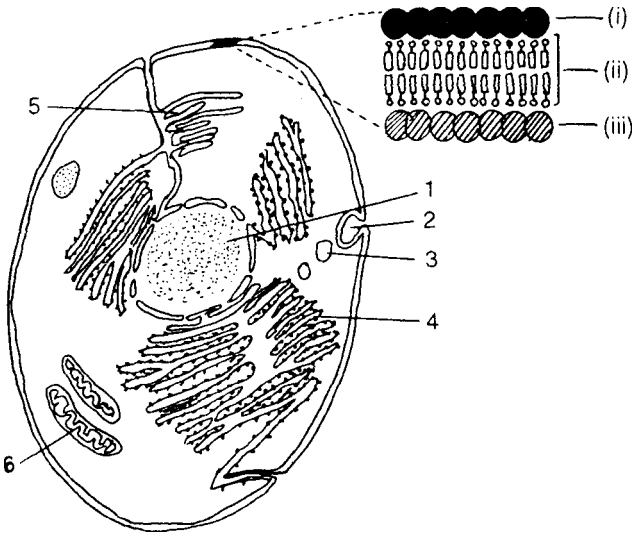

Fig.5: Diagrammatic representation of a 'typical' cell as seen under an electron microscope: *1.* nucleus; *2.* a vacuole about to be formed; *3.* vacuole; *4.* endoplasmic reticulum (rough); *5.* Golgi apparatus; *6.* mitochondria.

At the upper right corner, a model of the cell membrane has been depicted schematically: (i) outer protein layer; (ii) lipid layer; (iii) inner protein layer.

Within the cell, the most eye-catching structure is the spherical nucleus. The nucleus contains long, thin, coiled, thread-like entities called 'chromosomes'. Chromosomes carry the code for synthesis of proteins. One might say that what a cell does, and how it looks, depends upon the proteins it manufactures. Thus chromosomes carry the message for the activities and appearance of the cell.

Besides the nucleus, the cell contains a fluid matrix called the 'cytoplasm'. The structures present within the cytoplasm vary a lot, but among the important structures are the mitochondria, the 'power house' where the energy of various nutrients is tapped; ribosomes, where the proteins coded in the nucleus are synthesised; lysosomes, which can break down in the cell any substance requiring harsh treatment; and various types of vesicles and vacuoles containing products which have just entered the cell, or are about to leave the cell, or are being processed in the cell.

Most of these structures within the cell had been observed long ago with the aid of the light microscope. But the details of their structure were worked out only after the invention of the electron microscope. Compared with a light microscope, an electron microscope employs a beam of electrons instead of a beam of light. The wavelength of a beam of electrons being much shorter than that of visible light, it is possible to obtain a very high magnification without losing clarity.

The cell membrane, about 75Å [1Å (Angstrom)=10^{-10} metre=0.0000000001 metre] thick, when highly magnified, looks like a sandwich. It is three-layered with two similar layers enclosing a third different type of layer. The main constituents of the membrane are lipids and proteins. It is believed that they are arranged in the form of a bimolecular leaflet of lipids surrounded on either side by proteins. The membranes enclosing the nucleus and mitochondria are also simple variations of this basic pattern. The pores in the cell membrane through which transport of various substances takes place are so small that they

cannot be seen even by an electron microscope. Their existence has been postulated on the basis of functional studies.

The envelope that surrounds the nucleus, or the nuclear membrane, has large pores visible under the electron microscope. The pores provide a path for the passage of large nucleoprotein molecules from the nucleus to the cytoplasm. These molecules carry messages about the type of proteins to be synthesised in the cytoplasm.

The mitochondria are enclosed in a double membrane. The inner membrane is thrown into folds called 'cristae', thereby increasing its surface area. On the cristae are lodged the various enzymes required for harnessing energy from energy-rich compounds. The breaking up of these compounds is in many steps, and the enzymes are arranged in the same sequence as they are required. Mitochondria do not remain fixed at a particular position in the cell. Their movement is particularly striking in nerve cells where they may move several feet while travelling from the region of formation to where they are required to function.

The ribosomes are particles, about 100Å in diameter. They are attached to a system of membranous tubules called 'rough endoplasmic reticulum'. In cells engaged in extensive protein secretion, the proteins formed on the ribosomes are concentrated in a system of vesicles or flat membranous cisterns called the 'Golgi apparatus'. From time to time a vesicle is pinched off from the Golgi apparatus, moves towards the surface of the cell, and discharges its contents to the exterior.

On the one hand, materials are discharged to the exterior; on the other hand, particles, and even organisms like bacteria, may be engulfed by some cells from the exterior (phagocytosis). They get walled off in a vacuole which fuses with lysosomes. The enzymes present in lysosomes break down the contents of the vacuole into simpler products. Among them, the useful substances are

retained by the cell, and the waste products are discharged to the exterior.

Every cell is like a factory where a central authority (nucleus) issues instructions for some products (proteins) to be made by the highly skilled workers (ribosomes) with the help of energy generated in the power house (mitochondria) with many other skilled and unskilled workers doing various peripheral duties. It is this type of organised activity that we call 'life', and the cell is the smallest unit of an individual that displays it.

The hallmark of life displayed by each cell, however, is the ability to reproduce. Most of the cells in the body divide into two cells at a time.* Each daughter cell is a copy of the mother cell, and contains a nucleus having exactly the same number and type of chromosomes as the mother cell.

Cell division is necessary during growth, and also later on in life for replacement of dead cells. The ability of the cells to divide varies in different parts of the body. Parts of the body which are subject to considerable trauma, e.g. the skin or the intestine, continually lose cells. Correspondingly, these are the parts which have the most brisk cell division. Highly specialised cells like those of the brain do not divide at all. It is indeed marvellous that cell division continues for decades, and yet produces exactly the same type of cells as the mother cell, and in just the right number. Occasionally something may go wrong with this fine regulation, and cells may proliferate far too rapidly. When that happens, generally the cells produced are also functionally useless. Such a situation is called 'cancer'. Thus, a patient having cancer has in his body, to start with, a focus where useless cells are being produced like mad.

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* The cautious expression 'most of the cells' has been used with two deviations in mind. First, some cells, such as neurons (nerve cells) do not divide after birth. Second, germinal cells (in reproductive organs) divide but the daughter cells contain nuclei having half the number of chromosomes as compared to the mother cell.

These cells perform no useful function but that does not prevent them from obstructing normal function. Also, these abnormal cells consume energy commensurate with their rate of division, thus making their victims malnourished. As time passes, the original site of cancer may no longer suffice for the growing needs of the tumour, and pieces of it get pinched off and travel via the bloodstream to more hospitable sites, such as the liver and lungs. The tumour cells continue their mischief wherever they travel till various parts of the patient's body function very poorly indeed, and he just cannot meet the heavy nutritional demands of the unwanted cells. This, briefly, is the typical story of the unfortunate person afflicted with cancer somewhere in the body. Unfortunately we do not fully understand what makes the cells behave in this fashion. The causes certainly are multiple, and are different for different cancers. In some cases, the predominant cause is a virus, in some cases a chemical, and in some cases a chronic irritant, e.g. cigarette smoke. The chief lines of treatment of cancer are drugs, radiation and surgery. Drugs and radiation affect cancer cells adversely, but they do not entirely spare cells in the body that normally divide rapidly, e.g. the intestinal cells. Hence, the drugs and radiation employed for cancer treatment lead to serious side effects. Surgery is useful only in early stages when the growth is still small, and cancer cells have not spread all over the body.

In spite of all the recent advances in our understanding of cancer, the outlook continues to be far from rosy. But a ray of hope has emerged from a new way of approaching the issue which has been advocated by a surgeon, Bernie Siegel. What Dr Siegel, who prefers to be called Bernie, advocates is that although the cancer may be incurable, the life of a cancer patient can be healed through an appropriate change of attitude. The new attitude has two principal elements. First, the patient should extend his sphere of love to include as many new people as possible.

Second, the patient should learn to assert himself, be himself, and live the type of life he always wanted but could not, due to his tendency to always comply and conform. In other words, his love should include self-love. Surprisingly, the change of attitude not only enables the patient to make the most of the remainder of his life, the remainder also tends to get longer. Thus the approach adds both quality and quantity to the life of the patient. The similarity between this approach and the paths, such as yoga, which lead to spiritual growth, is unmistakable.

Organisation of Cells

The millions of cells of a man are grouped into somewhat poorly demarcated systems such as the circulatory system,

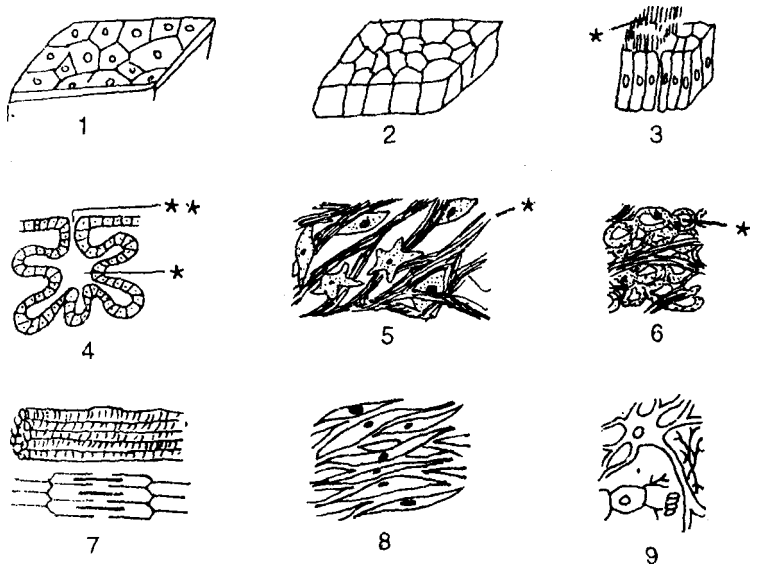

Fig.6: An assortment of tissues: *1-3*.epithelial tissues (lining tissues),*cilia; *4*. a gland lined by epithelium,*cavity of the gland containing the secretion, **opening for discharging the secretion; *5*. connective tissue (for connecting structures and filling spaces),*fibres; *6*. adipose (fat) tissue,*fat; *7-8*. muscle tissue; *9*. nervous tissue.

respiratory system, digestive system, and nervous system. Each system is composed of a number of organs, for instance the digestive system comprises mouth, salivary glands, food-pipe, stomach, intestines, etc. Each organ is further composed of a number of tissues (Fig. 6). A tissue is a collection of similar cells playing a discrete role in the function of an organ. For instance, within the lungs there would be tissues concerned with exchange of gases, and tissues imparting elasticity to the lungs.

One Cell—One Animal

There are also some animals which are entirely made up of a single cell. One such animal is called 'amoeba'. These animals are thought to be among the earliest that appeared on earth. These animals can ingest nutrition at any point on the surface, digest and utilise their food within their tiny body, discharge the waste products from their surface into the mighty sea that surrounds them and reproduce by dividing into two similar cells. Because of the huge volume of water surrounding them, and their own tiny size, they can maintain a steady and healthy composition in their interior without spoiling their environment.

Man and other large animals are not as different from an amoeba as they appear (Fig. 7). It is only that because of our large size and terrestrial existence, our problems are more complex, and they have been solved by complex mechanisms. We are not surrounded by sea but we have carried a bit of the 'sea' within us. Because of our large size, we have had to develop a tubular tree (circulatory system) to transport and distribute the sea to every cell of our body. The circulatory system is aided by a pump (heart) which keeps the 'sea' in motion. Because the small volume of the 'sea' within us does not provide much dilution of our waste products, we have developed special mechanisms to cleanse the environment of our cells. Finally, because of our complex organisation, we need co-ordinating mechanisms to match the activities of the various

cells of our body. For instance, when we sit down to a meal, the stomach should know that it will soon get busy

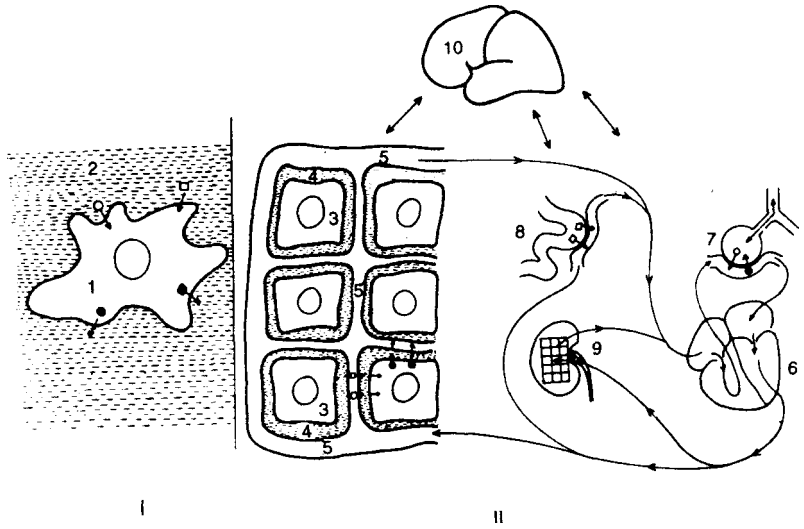

Fig.7: Amoeba (I) and man (II). The amoeba (*1*) is surrounded by sea-water (2); the organism exchanges nutrients and waste products directly with the sea-water; the cells of man (*3*) are not very different, being surrounded by the intercellular fluid (*4*) very similar to sea-water in its composition. The fluid passes on the nutrients from the blood to the cells, and the waste products in the reverse direction. Blood is taken to the cells by the arterial system (5) which branches off into capillaries (5') so as to take the blood close to every cell. The blood, having given the nutrients to the cells, and having collected the waste products, joins the venous system. The blood is kept in motion by the heart (*6*). Nutrients are replenished and waste products finally discharged by exchanges taking place chiefly in the lungs (*7*), intestines (*8*) and kidneys (*9*). The cells of the heart, lungs, intestines and kidneys are also supplied by blood in the same way as shown for other cells (*3*). Because the entire system is complex, its different components need to be co-ordinated. This function is performed by the nervous and endocrine system, shown symbolically in this diagram, by the brain (*10*). ○=Oxygen; □ =Other nutrients; ● =carbon dioxide; ■ other waste products.

so that it can get ready with its digestive juices; and during exercise, the muscles put to use should receive more nutrition through controlled overactivity of the breathing and circulatory systems. All these transport, distribution, cleansing and co-ordinating mechanisms will be dealt with in the subsequent chapters.

Similar but not the Same

We are all made up of similar cells, but are obviously not the same in every respect. The colour of our eyes, hair or skin is different. Some of us have curly hair and others straight; some of us have a long nose and others a short one. The secret behind this variation is located in the nuclei of our cells. The nucleus of each cell of a human being has 46 chromosomes (Fig. 8). Not only is their number constant,

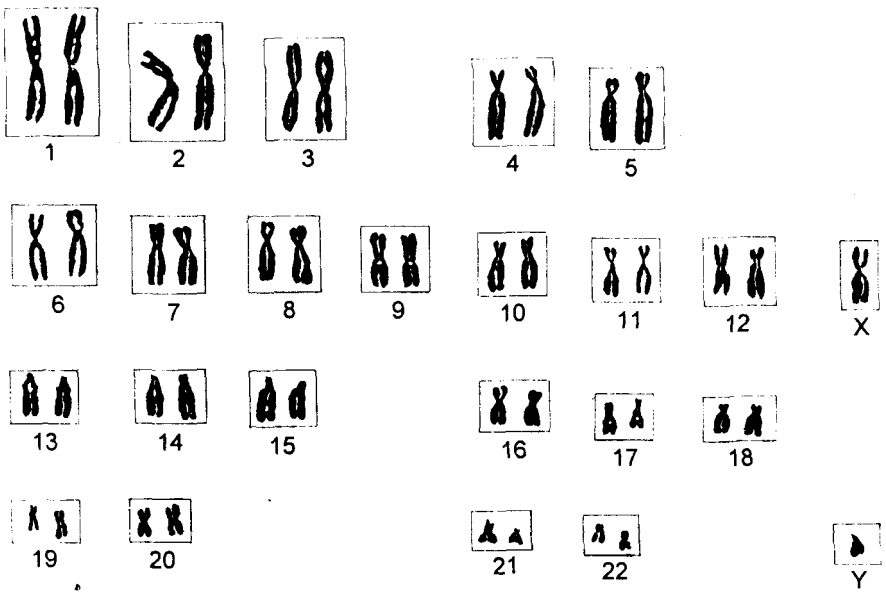

Fig.8: The chromosomes of a normal human male. Note the twenty-two pairs of autosomes and the pair of sex chromosomes (X and Y); in a female, both sex chromosomes are of the X variety. (*Courtesy*: Dr I.C. Verma, Head, Genetics Unit, AIIMS, New Delhi.)

the shape of chromosomes is also rather constant. The forty-six chromosomes in each cell can be sorted out into twenty-three pairs, the two members of each pair being apparently similar. Similarity in the number and shape of chromosomes is responsible for the similarity of all human beings. However, underneath this similarity of chromosomes are minute molecular differences. These minute differences are responsible for the differences between individuals. Each chromosome codes for hundreds of characteristics. The portion of a chromosome that codes for one character is called a 'gene'. Corresponding portions of two chromosomes belonging to a pair have genes for the same character, e.g. colour of eyes. But one of them may code for dark eyes, another for grey eyes. The individual will, however, have the character coded by one of them (called the 'dominant character'). For instance, if in the above example, 'dark eyes' is the dominant character, the individual will have dark eyes although he is carrying genes for dark as well as grey eyes.

The key substance making up the chromosomes is deoxyribonucleic acid (DNA). When a cell divides, the DNA also doubles in quantity, so that each daughter cell receives its full quota. Not only is the sharing quantitatively exact, it is also qualitatively an exact replica of the mother cell down to every single molecule. That is how the characters of an individual are maintained. Further, the molecular details of DNA in different individuals are not entirely identical. The greater the differences, the greater the dissimilarities between individuals.

DNA codes for characters through the agency of proteins. The nature of DNA determines the nature of proteins that a cell makes. What a cell does, and how it looks, depends on the proteins it makes. A protein, or a group of proteins, determines a character, such as the colour of the eyes.

Inheritance of Characters

It was mentioned above that when cells divide, they form

daughter cells having exactly the same number of chromosomes as the parent cells. This is true of all cells in the body except some selected cells in our sex organs. When these cells divide, they form cells having only one representative from each pair of chromosomes. Thus in human beings, these cells would have only twenty-three chromosomes—one from each pair. These cells are called 'gametes'. The gametes formed by men are called 'sperms'; those formed by women are called 'ova' (*singular*, 'ovum'). A new life begins when a sperm unites with an ovum in the mother's womb. During union, called 'fertilisation', the nuclei of the sperm and the ovum fuse into one and the resulting nucleus has forty-six chromosomes. All the cells of the child are now formed by repeated division of this united cell, called 'zygote'. Since its starting cell has twenty-three pairs of chromosomes, all the cells of his body also come to have the quota of chromosomes which is characteristic of all human beings.

Thus each of us has received half our chromosomes from the mother and half from the father. Since our parents also inherited their chromosomes in a similar way, and so on, our chromosomes have our whole ancestry inscribed on them. That is why we bear a resemblance not only to our parents but also to many other relatives.

The Human Genome Initiative

We have seen in a general way that characters are coded by genes, and that genes are located on chromosomes. How specific can we get on that point? For example, do we know which part of which chromosome codes for the colour of the eyes? Further, do we know in what precise detail what part of that chromosome differs in two persons, one of whom has black eyes and the other has blue eyes? Till now we cannot be so specific about all genes, but by the year 2005 we are likely to be, thanks to the human genome initiative. The initiative, commonly called the 'human genome project', is a multinational three billion-dollar

venture launched in 1990 by USA. It will require the participation of several countries around the world, including India. The human genome initiative is said to be the most ambitious scientific project ever undertaken in human history.

Let us see what the human genome project involves. We have twenty-three pairs of chromosomes, of which one pair (sex chromosomes) has dissimilar members in males. Thus there are twenty-four chromosomes (chromosomes 1-22, X and Y) to be studied. The twenty-four chromosomes have an estimated 100,000 genes coded by three billion nucleotides. Each of these nucleotides has one of four nitrogenous bases—adenine (A), thymine (T), guanine (G) or cytosine (C). What we need to do, therefore, are two things. *First*, find the gene on each portion of each chromosome. That will be the 'address' of the gene. For example, the address of a particular gene may be D 16 S40. Although it looks complex, the address may be interpreted as chromosome no. 16, block S, house no. 40. Further, the portion of a chromosome constituting one gene may have 10,000 nucleotides. We should know the exact sequence of these nucleotides in terms of A's, T's, G's and C's. That is the *second* thing we have to do. The human genome project will be complete only when we have sequenced every 'house' in each of the twenty-four chromosomes. The magnitude of the task may be imagined from the fact that if each nucleotide were to be written as just one letter (A, T, G or C), printing all the three billion letters would result in books equivalent to thirteen sets of *Encyclopaedia Britannica*.

Why has the human genome project been launched? Is it mere curiosity, or is it likely to be of some use? Opinion is divided on this issue in two respects. First, not everyone is convinced that the knowledge gained from the project will be of much use. Secondly, many are sincerely and seriously apprehensive that all the uses to which the knowledge can possibly be put may not be ethically sound.

Let us first examine the potential uses. By the end of the project we are likely to know the precise error in DNA which is responsible for every hereditary disease. That would be the first step towards therapy which might attempt to insert the error-free DNA at the right place. Further, it may make it possible to know in advance who is likely to develop in later life one of the diseases which have a strong hereditary predeliction, such as diabetes, heart disease, Alzheimer's disease or breast cancer. An early warning may help initiate precautions early in life which could prevent or delay the onset of the disease. Here is where some problems also begin. For example, should a woman undergo mastectomy just because she has a high probability of getting breast cancer at a later date? A day might come when any individual may be able to have his entire genetic profile worked out. The data may be fed into a computer to get his potential strengths and weaknesses and predict illnesses: a sort of modern horoscope. If that becomes possible, it raises the question whether society will tend to classify human beings on the basis of their genes? Will individuals with certain genes be stigmatised or discriminated against? In order to prevent such misuse, can information about individual genomes be kept confidential? These are the types of complex social, ethical and legal issues we are likely to face in the not-too-distant future.

Nature vs Nurture

A person's characteristics do not depend entirely upon his heredity. Heredity and environmental factors together shape an individual.

The influence of heredity on physical features is marked and ordinarily irreversible. Besides, heredity does influence behaviour and mental make-up also. How else can one explain the immense diversity in personalities and intellectual calibre of orphans brought up together in the same surroundings? However, brothers and sisters, in spite

of their very similar heredity, grow up to be very different types of individuals if brought up in different conditions, thereby illustrating the influence of environment. Thus, heredity and environment, both contribute to the development of an individual. The relative contribution of the two factors is the topic of a perennial debate. On one side are the idealists who believe that we are all born the same, and on the other are the racialists who feel that some races are intrinsically better because of their superior genetic make-up. While the racialist is wrong because very dull, average and very bright individuals have a similar distribution in every race, the idealist should also understand that we are all born with different potentialities. We are all born equal, but not the same. None is born superior or inferior, but all are born different. This understanding should help us in adopting a more rational and sympathetic attitude towards the less talented ones who, due to no fault of theirs, do not have a good enough genetic make-up or have not been able to live in a sufficiently stimulating environment.

3

BLOOD: THE VITAL FLUID

Only a living animal bleeds on injury; a dead animal does not bleed. It is probably owing to this observation that blood has been associated with life since times immemorial. The association persists even today, and is quite true. Devotion to God, country or humanity has often been expressed by willingness to sacrifice blood for their sake. Blood has, though incorrectly, also been considered the carrier of hereditary characteristics, hence, the expressions like 'blue blood', 'royal blood', and so on. But today we are quite clear about the role of chromosomes in genetic transmission, and know that blood has no direct relationship with heredity (Chapter 2). The sentiments attached to blood may not be justified, but blood is certainly the vital fluid of life. It is constantly on the move, visiting every cell of the body, distributing nutrients and collecting waste. Besides, it also has an important role in defending the body from infective agents and other insults.

Composition of Blood

Blood looks like a homogeneous red fluid to the unaided eye. But when it is spread into a thin layer and observed under a microscope, it is found to be a suspension of different types of cells in a liquid called the 'plasma' (Fig. 9). Most of the cells are faint yellow, and without a nucleus. A dense accumulation of these cells is responsible for the red colour of the blood. That is why these cells are called 'erythrocytes' or red blood cells. Besides red blood cells, there is a much smaller number of two other types of

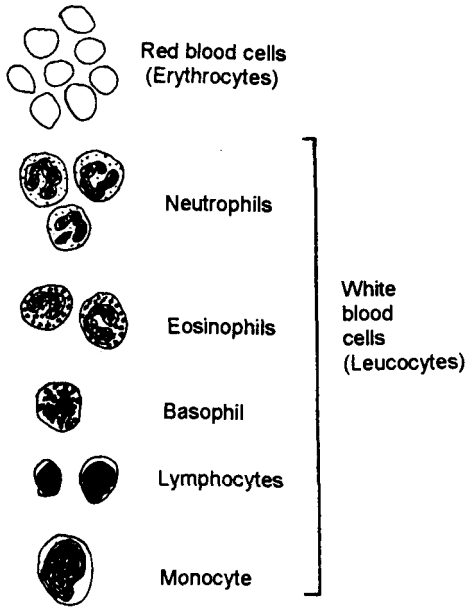

Fig.9: Different types of cells found in human blood: (a) erythrocytes, or red blood cells; (b) leucocytes, or white blood cells; (c) thrombocytes, or platelets.

cells—the 'leucocytes' or white blood cells (in fact colourless) and the 'thrombocytes' or platelets (because they resemble small plates).

Plasma

Plasma is a straw coloured liquid, about 90 per cent of which is water. The rest are solids, of which a *small* fraction consists of salts. The chief salt dissolved in plasma is sodium chloride, or common table salt. The salinity of plasma is approximately one-third that of sea-water, reminding us of our aquatic origin (Fig. 7 in Chapter 2). The discrepancy in salt concentration is possibly because when life originated, the sea was not as salty as it is today. The largest fraction of solids in the plasma consists of a variety

of proteins. One of the proteins (fibrinogen) is essential for clotting of blood. Some other proteins (globulins) aid in the defence mechanisms of the body. Some plasma proteins belong to the family of chemical messengers. Besides, many of the plasma proteins carry small molecules of the chemical messengers, and minerals like iron, copper or calcium. The binding of these substances to proteins helps in their safe delivery to their destination, and prevents them from getting lost while circulating in the blood-stream. The small molecules may be compared to small children, who run the risk of getting lost on their way to or from school unless accompanied by an escort (here, plasma proteins).

In addition to all the above substances, digested foods like glucose, fatty acids and amino acids, and waste products like carbon dioxide and urea are also transported in the plasma.

Red Blood Cells

Red blood cells are the most numerous of the blood cells. Each cubic millimetre of blood, which is about the volume of a pinhead, contains five million red blood cells. Two drops of blood contain as many red cells as the population of India. The red cells have undergone so much metamorphosis in the process of adaptation for a specific function that they are hardly recognisable as cells. They neither have a nucleus nor mitochondria. They are essentially small microscopic bags of haemoglobin, a reddish coloured protein containing iron. Haemoglobin has a remarkable affinity for oxygen. But it gives up its oxygen in conditions of oxygen lack. Thus haemoglobin makes it possible to deliver oxygen to tissues which need it. On the other hand, in the presence of excess oxygen, haemoglobin soaks up oxygen like a sponge. This takes place in the lungs. The cells of the body always have less oxygen than the blood which comes after passing through the lungs. Therefore, haemoglobin carries the oxygen it picks up in the lungs,

and places it at the disposal of the cells.

Haemoglobin has about 200 times as much affinity for carbon monoxide gas as for oxygen. The result is that even in small concentrations, carbon monoxide acts as a very strong competitor of oxygen for getting attached to haemoglobin. Further, once attached, haemoglobin does not easily surrender the carbon monoxide. Therefore, levels of carbon monoxide above a certain minimum can block enough haemoglobin so as to leave very little for combining with oxygen. In such a situation, the oxygen carried by the blood would fall to very low levels and lead to deficiency of oxygen delivered to the cells. With a dangerously low supply of oxygen, cells of the body cannot live. Therefore, carbon monoxide acts as a poison, and can cause death. Carbon monoxide is a component of smoke. Therefore, it is important that one does not sleep in a poorly ventilated room which has been kept warm by a smouldering fire. Cigarette smoke, and the smoke emanating from automobile exhausts, also have carbon monoxide. While smoking, 2-10 per cent of a smoker's haemoglobin combines with carbon monoxide, and is thereby rendered physiologically useless. The effect would be compounded in an area with high traffic density.

The normal quantity of haemoglobin present in blood is 12-15 g in every 100 ml* of blood. A decrease in this quantity is called 'anaemia'. Since haemoglobin is responsible for the red colour of the blood, and to some extent also that of the skin and mucous membranes,** anaemia results in reduced redness (pallor) of the skin and mucous membranes. The best region to assess the quantity

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* ml stands for millilitre. It is a unit of volume, and designates the space occupied by a cube, each side of which is one centimetre; one millilitre is thus the same as one cubic centimetre (cc).

** Mucous membrane is the name given to the lining of the internal organs of the body, e.g. the mouth, stomach or urinary bladder. It is much more delicate than the skin which lines the outside of the body.

of haemoglobin is the mucous membrane of the roof of the mouth (palate).

In order to understand why a person might have anaemia, it is essential to understand that the red blood cells in the body are not static. Old red blood cells keep getting destroyed as they get old, and fresh young cells keep replacing them. The average life span of a red cell is about four months. Even so, because of their large number, the body has to manufacture trillions of red cells every day. The factory where they are produced is located in the hollow of the bones (bone marrow). They are formed by the transformation of undifferentiated cells which have a nucleus but no haemoglobin. Gradually the precursor cell loses its capacity to divide, sheds its nucleus, and acquires haemoglobin. The young red blood cell is then released into the bloodstream. It is jostled around from place to place for about four months. During this period it grows old. When it loses its vitality, it is trapped by the spleen or the liver and broken up into its components. Most of the essential components remain within the body and are used again to form fresh red cells.

Logically then, anaemia can result from decreased production or increased destruction of red cells, or from abnormal blood losses. In our country, the commonest causes of anaemia are:

- Decreased production due to deficiency of iron, folic acid or proteins, which are required for the manufacture of red cells. The deficiency is particularly seen when the requirements of nutrients are increased, as during childbearing, nursing and childhood.
- Abnormal loss of blood. A common abnormal loss of blood is in women due to excessively heavy menses.

Presence of hookworms in the intestines too can cause loss of blood. Hookworms are about a centimetre long, thread-like worms, which cling to the walls of the intestines by means of their tiny teeth. Their teeth, though tiny, are sharp enough to cause a little bleeding. For one variety

of hookworms, it has been estimated that each worm sucks blood at the rate of 0.03 ml/day or about one ml/month. That may appear to be a minor loss. But keeping in mind that the number of worms harboured by a patient runs in hundreds, and may go up to a thousand, the loss over a period of a few months is substantial. In a hypothetical case, a patient harbouring 500 worms would lose about half a litre of blood in one month. It is difficult for the red cell producing mechanisms to compensate for such a heavy loss, and hence, the anaemia.

Accordingly, the treatment of anaemia depends upon its cause. If it is due to a dietary deficiency, the deficiency should be made up. If it is due to abnormal loss of blood, the underlying disease should be treated.

White Blood Cells

White blood cells are far less numerous than the red cells, the ratio being one white cell to every 600 red cells. They are, on the average, slightly larger than the red cells, and differ from them in three important respects. First, they have nuclei. Secondly, they do not contain haemoglobin, and are therefore nearly colourless; that is why they cannot be seen under the microscope unless coloured by some special chemicals. Finally, some white cells can move and engulf particles or bacteria much like an amoeba. The process is called 'phagocytosis' (*see* Fig. 29 in Chapter 9). Phagocytosis is one of the defence mechanisms of the body.

White blood cells are further subdivided into five groups according to the microscopic appearance they assume when stained by some popular dyes:

- *Neutrophils*, with a lobed nucleus and purple granules in the cytoplasm. They are highly phagocytic in nature.
- *Eosinophils*, with a lobed nucleus and red granules in the cytoplasm. They are associated with allergies. Probably they reduce the ferocity of allergic reactions.
- *Basophils*, with a lobed nucleus and blue granules in

the cytoplasm. They are probably important for healing.

- *Lymphocytes*, with a large round nucleus, almost occupying the whole cell. They are intimately associated with the immunological defence mechanisms of the body.
- *Monocytes*, with a kidney shaped nucleus and no granules in the cytoplasm. They are a part of the phagocytic system of the body.

Platelets

Platelets are much smaller than red or white blood cells and are devoid of nuclei. Their number is intermediate between that of red and white blood cells, there being one platelet to around twenty red cells. Platelets are, in fact, mere fragments of a cell. However, days are gone when they were considered artefacts. Today they are known to be mini laboratories containing more than eighty biologically active substances. Probably we do not still know all the functions of platelets. The best understood, and perhaps the most important, role they play in the body is in checking the bleeding from an injury (haemostasis: *haima*, 'blood'; *stasis*, 'standing').

Haemostasis: Whenever there is an injury to the body, except in unusually severe injuries, the bleeding normally stops within a few minutes. This is brought about, first, by an immediate narrowing of the small blood vessels at the site of injury. Platelets contribute to this step by liberating a chemical called 'serotonin'. In minor injuries, narrowing of blood vessels may be enough to stop bleeding within a few seconds. If it is not enough, the platelets start collecting at the site of injury and form a plug which blocks the bleeding site. But this plug is not firm enough to stop all oozing. Hence follows the next step wherein the blood which is oozing out itself forms a solid mass (clot).

Clotting (or coagulation) of blood is a complex process during which one of the plasma proteins (fibrinogen)

forms a lacy mesh in which the various blood cells get entangled. Within a few minutes, the clot becomes more firm by the fibrous strands of the network getting pulled like a ligature (retraction of the clot). Platelets participate in the clotting process and are the sole agency responsible for retraction of the clot. Thus platelets participate in all aspects of haemostasis.

Blood Transfusion

In the 19th century, a German physician suggested that temperamentally incompatible couples could achieve a happier and more harmonious relationship by cross-transfusing their blood. Today no scientist would give this advice to save a marriage, but there are many situations where blood transfusion may save a life. Most of these situations are those in which the patient has lost a large volume of blood, as in injuries and surgical operations. Blood is best replaced by blood. No equally effective artificial substitute has yet been manufactured.*

It is common knowledge that anybody's blood cannot be transfused into anybody else. The bloods have to be compatible to avoid any harm to the recipient. The basis of compatibility is the similarity in the type (or group) of blood. Strictly speaking, probably no two bloods are exactly alike. But for practical purposes, the blood of an individual can be assigned to one of the four groups: A, B, AB and O. The classification is based on the type of substances present on the surface of red blood cells. The groups signify whether a substance 'A' or 'B' is present, both are present or neither is present. For two bloods to be compatible, it is

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* In case blood is not available, saline (salt water) is infused in an emergency to replace the volume lost temporarily. If a high molecular weight substance like Dextran is added to the saline, it stays longer in circulation. Some fluorocarbons may be used as substitutes for oxygen-carrying function of the blood. However, a substitute for all functions of the blood is yet to be found.

not sufficient that their A B O group be the same, because there might be other differences between them. Therefore, in addition to matching of groups, before a blood transfusion is done, a drop from the blood of the donor and recipient each are actually brought in contact with each other in the laboratory and their behaviour observed under the microscope. If there is no damage to the red cells of the donor, the bloods are considered compatible.

Blood groups transcend all racial and geographic barriers. The group B blood of an Indian has as much chance of being compatible with a group B blood of an African or American as with a group B blood of another Indian. Blood groups do not respect family ties either; the blood of parents and children is not necessarily compatible.

It is not always possible to find a suitable donor whenever blood is required. Therefore, blood banks have been set up where a considerable quantity of blood of all groups is stored. Whenever a patient requiring blood transfusion comes, a suitable blood is selected from the bank and used for him. Thus a donor generally does not know who receives his blood, and therefore, does not suffer vain glory. The recipient is equally ignorant of the identity of the donor, and therefore, does not suffer obligation or embarrassment. That makes blood donation an ideal donation. The volume of blood removed at a time from the donor is only about one-tenth to one-fifteenth his total volume of blood. This bit of blood is hardly missed by a person in good health. The blood lost is replaced in a few weeks. Therefore, a blood donation can be safely made every three months. However, to increase the margin of safety, one might donate the blood only once or twice a year. Professional donors donate blood because they need the money they get for it. Because of the circumstances which compel them to sell their blood, they donate blood more frequently than they should, are undernourished and anaemic, and often conceal having had malaria, jaundice, or veneral diseases, which may be transmitted to recipients through their blood.

Testing of Blood

Blood, being the carrier of the body, mirrors the changes taking place everywhere in the body. Therefore, it is often tested in many diverse diseases. The most commonly performed tests are:

- Estimation of haemoglobin.
- Counting of white blood cells. White blood cells, being involved in defence mechanisms, are increased in almost all infections and major injuries.
- Counting the relative percentage of different classes of white blood cells. The type of white blood cells which increase in different varieties of infection are different.
- The level of various substances in the blood. Blood levels can give valuable information about supply, production or disposal of a substance. For instance, decreased utilisation of glucose in diabetes gives rise to high levels of glucose in the blood; and decreased synthesis of proteins in a person with a diseased liver reduces the plasma proteins.
- Detection of bacteria. In many infections, the infecting organism is present in the bloodstream.

As can be seen from these few examples, blood tests may be of great diagnostic value in some cases. Besides, they also help in objective assessment of the treatment. If serial tests before and during treatment show a steady improvement, it supports the physician's approach to the patient and encourages them both.

Blood has rightly been considered the vital fluid. Loss of blood leads to death in much the same way as deprivation of air, water or food. It happens because blood brings these vital substances to the cells in every part of the body. By doing its many jobs of feeding, ventilating and protecting our cells, the blood keeps us alive.

4

BLOOD ON THE MOVE: HEART AND BLOOD VESSELS

We are alive only so long as our cells are alive. Our cells stay alive so long as they are supplied with nutrients and cleared of their waste products. Blood does this job for every cell of the body. But it is remarkable that it does so while moving in, and remaining essentially confined to, an extensively branched tree of tubular structures called 'blood vessels'. This is because there are portions of this tree which come very close to every cell of the body. These segments of the tree are called 'capillaries'. Of all the blood vessels, the diameter of the capillaries is the smallest, and their walls the thinnest. The walls of capillaries are only one-cell thick, and have pores which allow several blood-borne substances to pass through them.

Between the walls of the capillaries and the cells is a narrow space containing a fluid. It is this fluid which exchanges materials directly with the blood as well as the cells. This fluid is called 'lymph'. Lymph is formed by a bit of the water and nutrients seeping through the walls of the capillaries.

Nutrients, including oxygen, are present in a higher concentration in the blood than in the cells, and therefore, pass out of the bloodstream and move into the lymph. The lymph passes on these substances to the cells. Similarly, carbon dioxide and other waste products, being in a higher concentration in the cells than in the blood, move out of the cells into the lymph. The lymph passes them on to the blood.

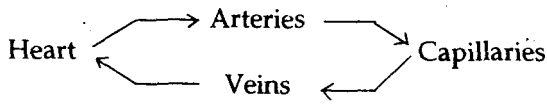
Thus each cell of the body is surrounded by a liquid containing food and oxygen in much the same way as in an amoeba. The lymph provides a private mini ocean to every cell with its attendant wetness, warmth and evenness.

How Blood reaches the Capillaries

Blood moves into the capillaries from the arteries. Arteries are large blood vessels which bring the blood from the heart. They divide and subdivide repeatedly into smaller arteries. A small artery enters every organ and divides into a network of capillaries within the organ. The capillary network is arranged in such a way that every cell is reasonably close to a capillary.

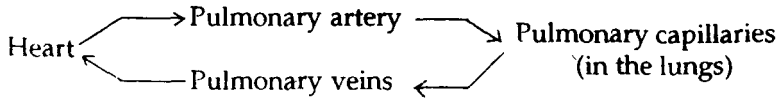
Where the Blood goes from the Capillaries

The blood leaving the capillaries enters small veins. Small veins unite to form large veins and so on, till finally two large veins are formed. One of them brings the blood from the upper parts of the body to the heart, the other brings it back from the lower parts of the body. The route of blood may thus be summarised as follows:



The above circuit is called the 'systemic circuit'.

It would be noticed that in the above circuit there is neither provision for replenishment of the oxygen which has been consumed by the cells, nor any explanation of how the carbon dioxide which has been dumped into the blood by the cells is finally removed from the body. This rejuvenation of blood is brought about by the lungs. For taking the blood to the lungs there is another circuit, the 'pulmonary circuit', which may be depicted as follows:



The pulmonary veins bring back the oxygenated blood from the lungs to the heart. It is this oxygenated blood that the heart pumps into the arteries of the body. An integrated picture of the two circuits is shown in Fig. 11 on p. 39.

At this juncture, one might mention the following facts, which are self-evident from the above discussion:

- All arteries carry blood away from the heart. All veins bring blood back to the heart.
- All arteries, except the pulmonary arteries, carry oxygenated blood. All veins, except the pulmonary veins, carry deoxygenated blood.*

Besides oxygen, there are other nutrients. Most of these are added to the blood while it passes through the digestive tract. Besides carbon dioxide, there are other waste products. They are removed from the blood in the kidneys. This does not mean that cells of the digestive tract themselves do not need nutrients, or that the cells of the kidneys do not produce waste products. It is only that while the blood is passing through these parts of the body, something happens to it which is in addition to what happens to it everywhere else. These facts have been depicted in Fig. 7, but the details of digestion and kidney function are given in subsequent chapters.

Heart: The Wonderful Pump

The major function of blood is transport, and clearly, to be able to perform its function, it must move. The push for the motion of blood is provided by the heart—a wonderful pump indeed which goes on working untiringly more than seventy times every minute, often for more than seventy

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* If these two sets of statements are not clearly understood, it is advisable to go back to the beginning of the chapter. The first statement gives the true distinction between arteries and veins. The second statement gives the basis as well as fallacy of the popular notion that arteries carry 'pure' blood while veins carry 'impure' blood.

years. From the earliest of times, man has realised the importance of the heart. Our language testifies to this fact, particularly the language of the poets. We talk of a man being broken hearted, or light hearted, and a meal can be hearty, as can congratulations.

The heart is fist-sized, weighs about 250 g, and is placed in the left side of the chest between the two lungs. Functionally speaking, the heart may be considered to consist of two pumps—the right heart and the left heart. The two sides of the heart are separated by an unbroken partition. Each side of the heart is further subdivided into two chambers by a perforated partition which is guarded

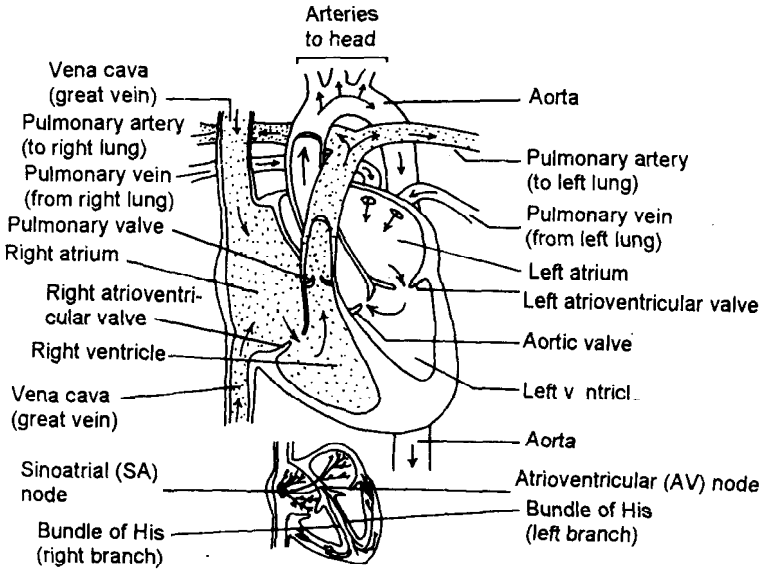

Fig.10: Structure of the human heart. The heart has been slit open to expose the various chambers, valves and openings of large blood vessels. In the small diagram below is shown the conducting tissue of the heart. The electrical impulse, generated rhythmically by the sinoatrial node, travels to the atrioventricular node, bundle of HIS and its two branches. (Adapted, by permission, from Weller, H. and Wiley, R.L.: *Basic Human Physiology*, 1979, Fig. 7.6, p. 119. *Courtesy*: D. van Nostrand Co., New York, USA.)

by a valve. On either side, one of the chambers is called the 'atrium', and the other 'ventricle'. Thus there are right atrium and right ventricle; left atrium and left ventricle (Fig. 10). Roughly speaking, only the ventricles are the pumps—the atria serve as reservoirs which pass on the blood to the ventricles for pumping. The left ventricle pumps the blood into the systemic circuit, while the right ventricle pumps it into the pulmonary circuit (Chapter 6). The flap valve separating an atrium from the corresponding ventricle allows the blood to flow only from the atrium towards the ventricle. Similarly the opening of the ventricle into the blood vessel into which it pumps the blood is also guarded by a valve so that the blood does not flow back from the blood vessel into the ventricle. Oxygenated blood leaves the lungs in the pulmonary veins (there are four of them) to reach the left atrium. From the left atrium, the blood enters the left ventricle. The left ventricle pumps it into the largest artery of the body (the aorta), which divides repeatedly to distribute the blood to capillaries all over the body.

After the exchange of substances has taken place in the capillaries, the blood from the whole body is ultimately collected in two large veins which bring it back to the right atrium. The right atrium passes on this blood to the right ventricle. The right ventricle pumps the blood into the pulmonary artery which carries it to the lungs where it is made ready for going to various parts of the body. It returns to the heart via the pulmonary veins, and thus the circle is completed (Fig. 11).

The first to work out this circle was William Harvey, an English physician who published his findings in 1628. What we have learnt in the last few pages was said by him in a book having seventeen chapters. Apart from the fact that he described in detail all the experiments which had led him to these conclusions, his verbosity is a tell-tale account of the atmosphere of his times. Those were the days when the stifling influence of authority had just started giving way to reason. That is why, to have some

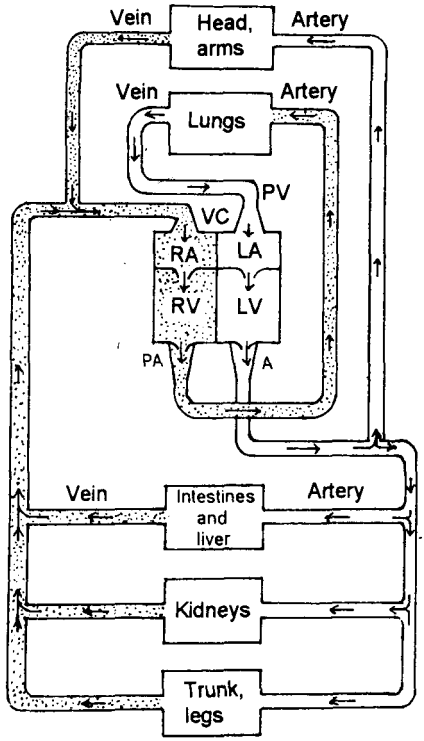

Fig.11: The systemic and pulmonary circulation: stippled 'blood', deoxygenated blood, clear 'blood', oxygenated blood.

hope of having his viewpoint accepted, he had to do a lot more experiments than were sufficient. He had to wait a lot before he had the courage to go to print, and his presentation is a masterpiece in completeness and power of argument. His apprehension is best illustrated in his own words: ". . .Not only do I fear danger to myself from the malice of a few, but I dread lest I have all men as enemies, so much does habit or doctrine once absorbed, driving deeply its roots, become second nature, and so much does reverence for antiquity influence all men." Fortunately, however, he had the satisfaction of seeing his work recognised during his lifetime.

So far the function of the heart has been outlined only vaguely. What it means in more scientific terms is that the heart provides a pressure head for the movement of blood. Blood, or any other fluid, moves from a higher pressure to a lower pressure. The ventricles pump blood into the arteries at a high pressure. The pressure in the arteries is higher than that in the capillaries. On the other hand, the pressure in the capillaries is higher than that in the veins. Therefore, from the capillaries the blood moves into the veins.

The pressure in the blood vessels depends not only upon the force with which the heart pumps the blood but also the diameter of the blood vessels. It is easy to imagine that the smaller the diameter, the higher will be the pressure in the blood vessels. So, if the lumen of the arteries gets narrowed by the deposition of some substances on their inner walls, the pressure in the arteries would rise. This is what is called 'high blood pressure'. It generally results from the deposition of fatty substances in the arteries. Apart from the hereditary tendency for the formation of these deposits, overeating, lack of physical work, prolonged mental stress, drinking and smoking seem to accelerate the process of deposition. High blood pressure harms the body mainly in two ways:

- Narrowing of the arteries reduces blood supply to many important organs, like the brain and kidney, and even the heart itself. This impairs the function of these organs.
- High pressure in the arteries makes it necessary that the left ventricle pumps the blood into them at still higher pressure. That, as we have seen, is necessary to maintain the flow of blood. Again, that, in turn, implies more vigorous contraction of the heart. Pumping hard imposes a strain on the left ventricle, and in the long run, on the entire heart and circulatory system, leading to impairment of the function of the heart.

The movement of blood within the heart is also in accordance with the slope of pressure. Blood flows from the veins into the atria while they are empty and relaxed because during this phase, the pressure in the atria is lower than that in the veins. During the same phase, the ventricles are contracting to pump the blood into the arteries. After ejecting a part of the blood into the arteries, the ventricles start relaxing. So the pressure in the ventricles falls. In the meantime, the atria fill up, and consequently their pressure rises above the venticular pressure. As a result, the valve between the atria and ventricles is forced open. The flow of blood into the ventricles, and their subsequent contraction raises the pressure in the ventricles above that in the atria, thus snapping the atrio-ventricular valves shut, and stopping the flow. Further ventricular contraction raises the pressure within their cavity, even above that in the arteries, forcing open the intervening valves and resulting in a flow of blood into the arteries. The initial gush of blood from the left ventricle into the aorta gives rise to a wave which is transmitted to all the arteries. This wave is commonly looked for at the wrist, and is called the 'pulse'. Since each pulse beat corresponds to a ventricular contraction, the rate at which the pulse is felt gives the heart rate, and its character reflects the 'character' of the heart beat. The pressure relationships outlined above can now be studied even in conscious human beings by introducing a fine polythene tube (catheter) into a vein, and pushing it further and further in till the catheter reaches the heart. By connecting the catheter to a pressure measuring device, one can measure the pressure in that part of the heart where the tip of the catheter is located.

In short (*see* Fig. 10), the heart beats in a definite sequence. First, the atria relax to fill up while the ventricles contract to send their contents into the arteries; then the atria contract to send their contents into relaxed ventricles. The orderly sequence of contraction is due to the presence of a specialised tissue in the heart, called the 'conduction

tissue'. It conducts an impulse of activity, electrical in nature, from the atria to the ventricles. When the electrical impulse reaches a chamber of the heart, contraction of the chamber follows immediately. The rate at which the impulse is carried varies in different parts of the heart. The impulse spreads within the atria or within the venticles very fast, so that both the atria, or both the ventricles, contract almost simultaneously. But at the junction of the atria and the ventricles the impulse is delayed considerably. That is why the atrial and ventricular contractions are not simultaneous. The origin of the impulse of activation is in a small region in the right atrium called the 'sino-atrial node (S-A node)'. Impulses originate in the S-A node rhythmically, and are conducted to both the atria and the ventricles by the conduction tissue. Thus the rate at which the heart beats is determined by the rate at which the S-A node generates the impulse. Since the S-A node sets the pace of the heart, it is called the 'pacemaker' of the heart.*

In some disease states, the impulse cannot be transmitted from the atria to the ventricles due to a block in the conduction tissue. Such a condition is called 'heart block'. In heart block, then, the S-A node cannot set the pace of the heart. The atria continue to beat at the rate at which the S-A node fires. But the impulse of atrial activation cannot pass to the ventricles. Therefore, the ventricles beat out of tune with the atria at their own characteristic rate which is much slower than the S-A node discharge rate. In such cases, sometimes it becomes necessary to supply artificial electrical impulses to the ventricles to keep them beating at the usual rate. Instruments used for this purpose are also called 'pacemakers'. Some pacemakers discharge continuously at a fixed rate, or at a rate that can be adjusted, while others

* The pacemaker is loosely comparable to the engine of a train. The wagons follow the engine, and their speed is determined by that of the engine. Not only that, if some of the wagons were replaced by engines, the speed would be set by the fastest of the engines.

discharge only when needed. These are called 'demand' pacemakers. The electrodes which actually stimulate the ventricles are made to reach there through a vein, much like a catheter. The leads from the electrodes are connected to an instrument which generates rhythmic impulses. This instrument may be worn like a belt, or it may be implanted in the chest wall by a surgical operation.

We have seen earlier that an electrical impulse precedes contraction. To elaborate a little more, the impulse gives rise to electrical changes in the membranes of the heart cells, which in turn are followed by the mechanical contraction. The electrical changes in individual cells are extremely weak, but the changes in many cells put together are strong enough to reach the surface of the body. They can be picked up by electrodes placed on the limbs or chest, and if suitably amplified, can be recorded on a paper. Such a record is called an 'electrocardiogram' (ECG), and has the configuration shown in Fig. 12. The configuration is altered in many disorders of the heart, and is, therefore, valuable to the doctor as a diagnostic aid.

The effectiveness of the heart as a pump can be assessed by the amount of blood pumped in unit time. This quantity is called the 'cardiac output', and is the product of the heart rate and the amount of blood pumped with every beat. The situation may be compared to walking, where the distance covered would depend upon the rate at

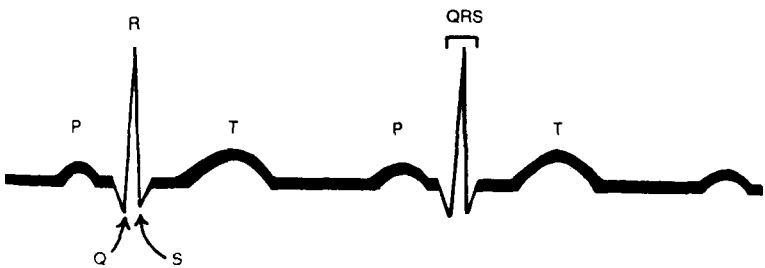

Fig.12: The configuration of a normal electrocardiogram. Each P-QRS-T waveform represents one heart beat.

which the steps are taken, and the length of each step. One can also understand that, beyond a reasonable limit, increasing one of the factors would adversely affect the other factor. For example, if one tries to walk faster by taking steps more frequently, the steps would also tend to get smaller. Similarly, in case of the heart also, increasing the heart rate beyond 180 per minute does not help in increasing the cardiac output, because the stroke volume starts getting correspondingly smaller. In a normal person each ventricle pumps about 5 litres of blood per minute, which is usually achieved by pumping about 70 ml of blood about 70 times every minute. When the requirements of the body for circulation of blood are increased, as in exercise, each ventricle may pump upto 140 ml of blood up to 180 times every minute, which gives a cardiac output of about 25 litres per minute. Thus the heart utilises only about one-fifth its maximal capacity while we are at rest.* That is why, mild impairment of the heart's function does not cause any inconvenience at rest and even during mild exercise. In athletes, the maximal capacity is even more. During their training and practice, the heart muscle gets stronger and the resting heart rate falls. For instance, a good athlete may achieve his resting cardiac output of 5 litres/minute by pumping 100 ml of blood fifty times every minute. During exercise, he can raise the cardiac output to even 40 litres/minute by pumping 220 ml of blood (he can do so because his heart muscle is stronger) 180 times every minute (faster than that is of no use).

From the above discussion emerges one more fact: the rate and force of heart beat do not have fixed and static values. The fluctuation is obvious to all of us from the way the heart starts pounding against the chest whenever we

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* The reserve capacity to the tune of 80 per cent is not exclusive to the heart. It is found in most parts of the body, including the lungs, liver and kidneys. The general phenomenon is sometimes referred to as physiological reserve.

are taxed physically or emotionally. There is a story of a pretty nurse who always subtracted ten from the pulse rate of her male patients, and arrived at the 'correct' rate. How does the heart know when to work harder? The answer lies largely in the communication systems of the body, the chemical messengers (hormones) and the nerves. These systems will be dealt with later (Chapters 12 and 13). Besides, the heart also has an internal regulation of its own. In exercise, for example, more blood is returned to the heart by the contraction of skeletal muscles and the resultant squeezing of the veins. This distends the heart. A distended heart tends to beat faster and harder in an attempt to overcome the distension.

Diseases of the Heart

Diseases of the heart excite popular interest because 'heart attack' is often in the news as the cause of death of many a famous personality. However, all diseases of the heart do not belong to this notorious category. There are three categories of heart disease which are relatively common.

Congenital Heart Disease: As the name indicates, these heart diseases are present right at birth. They are due to defective formation of heart in the mother's womb. In most cases, no cause can be pinpointed. However, avoiding drugs and infectious diseases during pregnancy may help in reducing the chance of such an accident. Keeping in view the complicated structure that the heart is, it is not surprising that in a few cases it is malformed. What is surprising is how it is so often normally formed.

Some of the babies having a congenital heart disease are born 'blue', i.e. their lips, nails, as well as skin have a bluish tinge. However, many of them do not have any such obvious sign. Therefore, it is necessary that every newborn baby be examined by a doctor for the early detection of any abnormality of the heart. As the child grows up, the heart disease shows up by slow growth and breathlessness while playing.

The treatment of congenital heart diseases is generally surgical wherein an attempt is made to correct any defect in one of the partitions or valves of the heart. Many surgically treated children live quite normal lives.

Rheumatic Heart Disease: This is again a curse that just visits some children, and it is difficult to pinpoint why it does. It usually starts as a sore throat—something very common, and usually innocuous. But occasionally, the sore throat is followed by pain and swelling in the joints (arthritis). In some of the children who get arthritis, the heart also gets involved. Every child gets sore throat but only a few of them get arthritis, and still fewer get the heart disease. Nobody can tell in advance who will get the heart disease. But the disease tends to run in some families, indicating a genetic predisposition, and is more common in poor socio-economic groups, suggesting the role of poor nutrition and/or hygiene.

In rheumatic heart disease, generally the valves of the heart are involved. The passages which they guard may become narrow (stenosis), and the valves may become leaky (valvular incompetence leading to regurgitation). One can help these children by:

- Treating promptly any child who gets joint pains following a sore throat.
- Treating a sore threat promptly and energetically in every child who gets joint pains or heart disease following a sore throat.
- Treating the heart disease at an early stage.

Coronary Heart Disease: This is the form of heart disease which is more widely known and dreaded. It generally affects individuals of a higher age group, though young persons are not immune.

To understand its genesis, one might start with the fundamental fact that, like every part of the body, the heart is also supplied nourishment by arteries. Blood flow through these arteries is indispensable to keep the heart nourished; the blood bathing the cavities of the heart all the time is

virtually useless for this purpose because of the large distance between the blood and the heart cells to be nourished. The arteries supplying blood to the heart are called 'coronary arteries'. Sometimes fatty substances are deposited on the inside of coronary arteries, thereby reducing the supply of blood to the heart. The effects of the reduced supply will be most felt when the requirements are enhanced, as in exercise or emotional upheavals. In such states, a portion of the heart may be damaged, and the person feels pain in the chest. However, any pain in the chest does not indicate heart disease. The pain should be precipitated by exertion or excitement, and should settle down when the precipitating factor has disappeared. Further, the pain gives choking sensation, giving the patient a feeling as if somebody is sitting on his chest. These points are important to understand because many persons get sleepless nights just because they start getting worried about a pain in the chest which has nothing to do with the heart. The pain may be muscular in origin, or it may be just 'imaginary'.

The disease process affecting the coronary arteries is similar to that affecting other arteries in high blood pressure. That is why, the two diseases often occur together. Hence, the predisposing factors and preventive measures are also similar, and they have already been discussed.

5

LUNGS: THE LIFE LINE

Blood in the capillaries keeps moving continually towards the veins. Blood flow from the arteries towards the capillaries is kept up by the contractions of the heart. Thus the heart works hard to supply fresh blood to every part of the body. But the effort of the heart would be of little use unless the fresh blood supplied is able to serve the tissues better than the blood which has been pushed out. This is possible only if the incoming blood has more nutrients and less waste products than the outgoing blood. Looking at it a little differently, there should be some points in the circulatory system, where nutrients can be added, and waste products removed from the bloodstream. One of the most important stations of this nature is constituted by the lungs. In the lungs oxygen is added to and carbon dioxide is removed from the blood.

The General Arrangement

Air enters the nose and proceeds towards the lungs. In the lungs, some oxygen is removed from the air taken in (inspired air), and some carbon dioxide added. Then the air returns to the nose and is expelled out (expired air). Because both the inlet and the outlet are at the nose, the entry and exit of air have to alternate with each other. They cannot go on simultaneously. The situation is comparable to a single-door bus where the passengers cannot enter and leave simultaneously. That is why it has been said by Anthony Smith that the lungs are a brilliant execution of a poor design. We have talked of the poor

design; the brilliance of execution will become apparent when we come to the process of gas exchange.

The Air-conditioners

Before the air enters the lungs, it has to pass through the nose and a tree of airways—the bronchial tree (Fig. 13). The trunk of the bronchial tree (trachea) is in the front of the neck and can be felt through the skin. The trachea has a series of rigid rings around it, which can also be felt. Such rings are also present in all the large branches of the bronchial tree. They make the airways non-collapsible, while leaving them flexible. The nose and airways do not serve only as conduits. They also warm, humidify and cleanse the air before it reaches the lungs—a treatment akin to air-conditioning. Preliminary cleansing of the air is done by the hair at the entrance to the nose. They strain out any coarse particles or tiny insects that may be swept in with the air flow. Finer cleaning is done deeper within the nose and airways by subtler devices. First, the path of the air through the nose is tortuous and moist. Both these

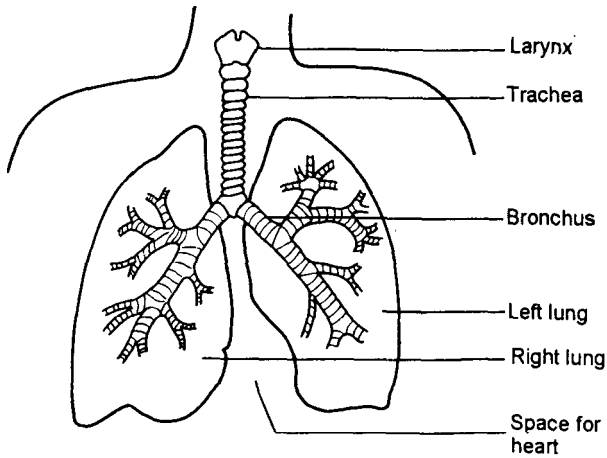

Fig.13: The respiratory airway tree and lungs.

factors make the probability of dust particles getting trapped very high indeed. Second, the airways are lined by cells which are moist and have minute hair-like processes (cilia) capable of rowing back and forth. They keep beating in a direction opposed to the direction of air flow so that any particles that have escaped all the traps laid for them are beaten back.

As a result of these mechanisms, the air generally enters the lungs in an amazingly clean state. But unfortunately the air in coal mines and industrial areas overwhelms even these well-designed mechanisms. Therefore, the lungs of coalmine workers, and of city dwellers, particularly smokers, keep getting a moderate dose of particulate matter and gradually get blackened due to the accumulation of these particles. Sometimes it is not just the industrialisation, but also our own habits to blame. Many of us fail to use all our cleansing mechanisms because we insist on breathing through the mouth. The mouth does not possess the contraptions for cleansing the air. Therefore, except when it is impossible to breathe through the nose, as in a nose-block, it is undesirable to breathe through the mouth.

Breathing In and Out

Breathing in is called 'inspiration' and breathing out is called 'expiration'. What moves the air in or out? The question appears complex but the answer is based on very simple mechanisms. Two basic principles are involved:

- As the space occupied by a fixed amount of gas* decreases, the pressure exerted by it increases, and

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* Gases are the most loosely arranged form of matter. They neither have a fixed shape nor volume. Air is principally a mixture of two colourless, and therefore, invisible gases—oxygen (20%) and nitrogen (80%). Nitrogen does not participate actively in the respiratory process, but makes air safe. Oxygen is a supporter of combustion, and if air were to be made only of oxygen, fires would destroy everything on earth, including ourselves.

vice-versa.

- Gases flow from a higher pressure to a lower pressure.
- Both these principles may be illustrated by an example.

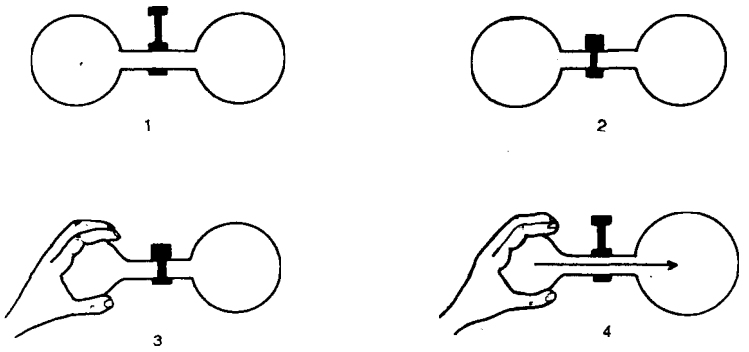

Fig.14: A simple mechanical model made up of two interconnected balloons to illustrate some physical principles underlying flow of air in the respiratory system.

Consider two interconnected balloons A and B with provision of a clamp for occluding the link between them whenever desired (Fig. 14). To start with, let them both be inflated to a moderate pressure while they are connected with each other (1). Then, let the clamp be used to occlude the connection (2). Let balloon A be squeezed with the hand. As the air contained in it is forced to occupy a smaller volume, the balloon can be felt to harden, i.e. the pressure within it increases. Thus a *decrease in volume leads to an increase in pressure.* If the balloon is kept compressed and the clamp released (3), some gas would leave balloon A to enter balloon B. This happens because the gas in A is at a higher pressure, than in B. *Thus gases move from a higher pressure to a lower pressure.*

Now let us see how these principles operate to bring about inspiration and expiration. If we observe the movements of our chest (thorax) and belly (abdomen) carefully,

we would find that during inspiration, they both expand. The chest expands by the upward movement of the ribs and breast bone (sternum). The ribs being curved in a characteristic fashion, their upward movement expands the chest sideways: the process has been compared to the movement of a bucket handle. The upward movement of the sternum expands the chest from front-backwards: the process has been compared to the movement of a pump handle (Fig. 15). The other major movement of inspiration involves the downward movement of the muscular dome-shaped partition between the thorax and the abdomen, called the 'diaphragm'. This movement enlarges the dimensions of the chest from above downwards. Simultaneously, this movement of the diaphragm also pushes the abdominal contents down, thereby making the belly bulge. In short, as a result of the movement of the ribs and diaphragm, the thorax enlarges in all its dimensions. Increase in the volume of gases within the chest decreases

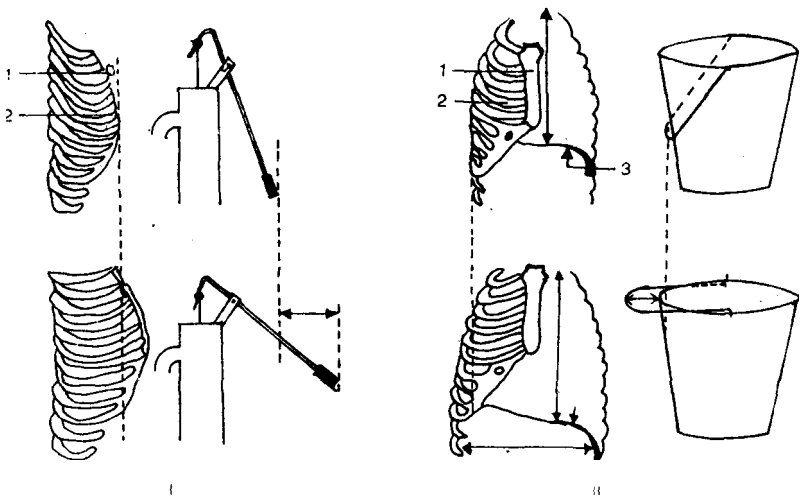

Fig.15: Chest excursions during inspiration and expiration: I. 'pump handle' movement; II. 'bucket handle' movement: *1.* Sternum (breast bone); *2.* ribs; *3.* diaphragm.

their pressure below the atmospheric pressure. As a result, air from the atmosphere rushes into the chest through the nose.

During expiration, the events of inspiration are reversed. The volume of the chest decreases and the pressure within it rises above the atmospheric pressure. This results in expulsion of gases from the chest into the atmosphere.

While breathing at rest, normally inspiration is active while expiration is passive. However, when breathing activity is increased as in exercise, or when breathing is difficult due to a disease, both inspiration and expiration may need active effort.

The relative participation of ribs and diaphragm in breathing depends upon habit and dress. Preferably, the garments should be loose around the chest as well as abdomen, so that both are free to expand. In pregnant women, breathing tends to be thoracic for obvious reasons. But there is good reason why it should be so common also in the rest of us. We should try to develop the habit of slow and deep abdominal breathing with the mouth closed. One way to do so is to spend some time every day on a few yogic exercises.

Mechanisms of Gas Exchange

The air in the lungs is not really within the body unless it reaches the bloodstream. The transfer takes place in the terminal portions of the airways. The fine terminal airways balloon out into a cluster of thin-walled air sacs which end in tiny air cells (alveoli). The wall of an alveolus (Fig. 16) is made up of only a single layer of very thin cells, and is covered with a tracery of capillaries. A man has about 600 million alveoli. If the entire alveolar surface available for gas exchange were spread out, it would occupy about 100 square metres—the area of a tennis court. The exchange of gases between the alveolus and the capillary is governed by the physical principle enunciated earlier, viz. that the gases move from higher to a lower

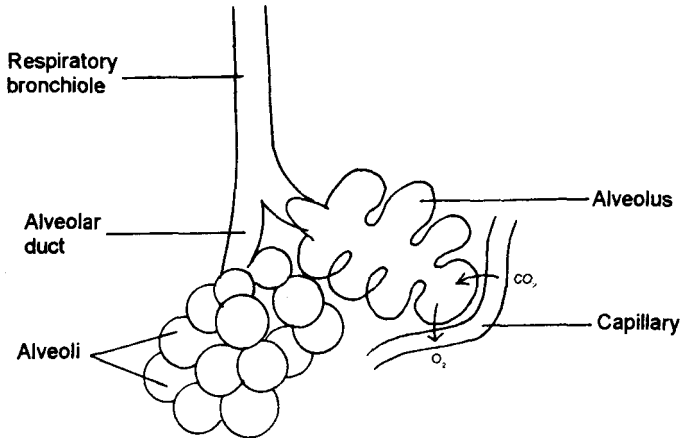

Fig.16: The gas-exchange unit of lungs. The respiratory bronchiole leads to alveolar sacs, each resembling a bunch of grapes. The alveoli are in intimate contact with capillaries of the lung. Oxygen is passed on to the capillaries, and carbon dioxide is collected from them.

pressure. Here we further have to keep in mind that the principle applies also to individual gases in a mixture of gases. Since the tissues consume oxygen from and add carbon dioxide to the blood, the blood flowing into the lungs has oxygen at a lower pressure and carbon dioxide at a higher pressure than in the alveoli. Therefore, oxygen moves from the alveoli into the blood and carbon dioxide moves out of the capillaries to enter the alveoli. The oxygenated blood then returns to the left atrium of the heart to be pumped to the various parts of the body.

Regulation of Breathing

It is an everyday observation that the breathing activity increases whenever the body uses up more oxygen and produces more carbon dioxide, as in exercise. How do we manage to breathe with a vigour that is necessary and just sufficient to keep pace with the requirements of the body? All the answers to this question are not known but some of the mechanisms involved are fairly well understood. These mechanisms are principally situated in the blood

vessels or in the brain, where oxygen and carbon dioxide concentrations of blood are sampled. In any case, the information is ultimately fed into and processed by the brain. The output of the brain is in the form of instructions to the respiratory muscles to work with a specified strength and frequency. The common feature of these regulating mechanisms is that they are triggered by excess of carbon dioxide or lack of oxygen. These triggers induce an increase in the rate and depth of breathing. In other words, respiration is stimulated by those changes in the composition of the blood which occur whenever respiratory activity is less than that warranted by the body's requirements. Increased respiratory activity brings in extra oxygen and washes off carbon dioxide, restoring the gases to their normal levels.

Normally the mechanism is so adjusted that a steady state is reached soon which is characterised by absence of quick changes in respiratory activity, and the cyclic changes in gas level are also negligible.

The involuntary control of respiration outlined above saves us the botheration of worrying about our breathing, no matter how busy or careless we are. It can be demonstrated by holding the breath. Since the body continues to use oxygen and produce carbon dioxide, breathholding leads to depletion of oxygen and accumulation of carbon dioxide. Both these factors being strong stimuli for vigorous breathing, there eventually results an uncontrollable urge to resume breathing. To commit suicide by holding the breath is well nigh impossible.

Besides the involuntary control of breathing which operates all the time, we can also superimpose voluntary control on our breathing. We can hold our breath or vary our rate and depth of breathing whenever we feel like it. Wilful modulation of breathing activity forms one of the most important aspects of swimming, singing and many athletic and yogic exercises.

6

FOOD: THE FUEL AND THE FRAME

All of us have to eat in order to live, even if we do not believe in living to eat. Eating is an act we repeat several times a day, day after day, but in spite of it, or perhaps because of it, we seldom pause to think seriously the purpose of this endless exercise. However, it is easy to guess the functions of food. First, it gives energy. Energy is

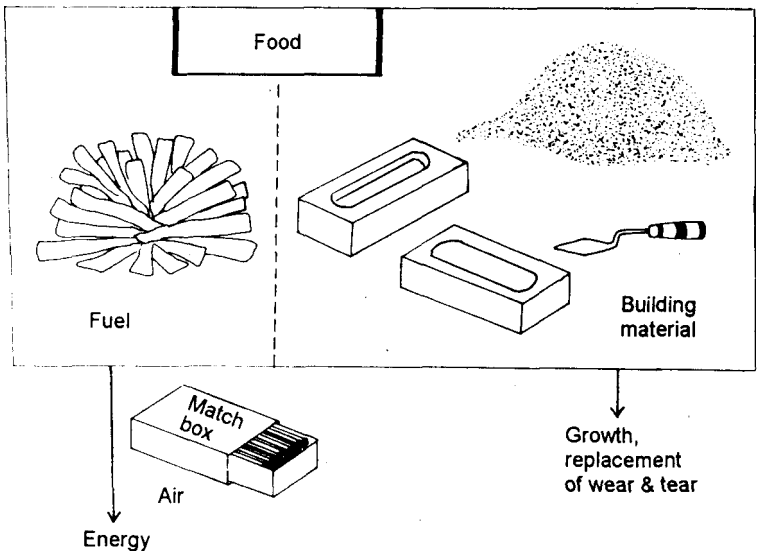

Fig.17: The functions of food. Food serves as fuel which the body burns for obtaining energy. Oxygen in the air is necessary to burn it, just as a match is needed to light ordinary fuel. Food also serves as building material for growth during childhood and for replacement of living matter lost through normal wear and tear.

required not only for work and play but also for activities basic to life itself, e.g. beating of the heart, breathing, and working of the kidneys, liver and brain. Thus, even if there is a patient resting on bed all twenty-four hours a day, he would need energy, and hence food. In fact, just staying alive needs about as much energy as hard physical work. In other words, a hardworking man, like a carpenter or a soldier, uses about half his food for processes basic to life, and uses the other half for all the work he does. Another function of food is to form new living matter. New living matter is obviously formed in children and manifests as growth. Although neither as obvious nor vigorous, the process goes on in adults as well for replacement of tissue wear and tear. So, the second function of food is to provide building material for formation of fresh living matter (Fig. 17).

Types of Nutrients

The human body is equipped to burn three classes of chemicals for procuring energy. They are carbohydrates, fats and proteins. But for manufacturing new living matter, we need rather more of the proteins. Protein foods are expensive; it is a waste to use them as fuel. Therefore, the diet should be so arranged that the energy requirements can be met from carbohydrates and fats, sparing proteins for building the body.

Starch is the most abundant carbohydrate in the diet. It is obtained largely from cereals and potatoes. Sugar is also a carbohydrate. The body uses part of the carbohydrates to get energy. Some of it is converted into building blocks of proteins, the amino acids. Some carbohydrate is stored as glycogen in the liver and muscles. Surplus carbohydrate can be converted into fat.

Proteins are made up of a large number of building blocks called 'amino acids'. There are only about twenty different amino acids but the number of proteins they make is far greater, just as only twenty-six letters of the alphabet can make so many words. For efficient body

building, our food should be able to provide all the amino acids in optimal quantities. Fortunately, the body itself can manufacture more than half the amino acids from carbohydrate and fat sources as well. Those which the body cannot make must come from food, and are called 'essential amino acids'. Animal proteins contain all of them in about the same proportion as the human body, and are therefore, better than vegetable proteins which are usually deficient in one or more essential amino acid. However, in a judicious mixture of two vegetable proteins, one component can compensate for the deficiencies of the other and prove as good as an animal protein (Fig. 18). Cereals and pulses form an ideal combination in this respect. Thus *khichri* is not to be dismissed as a food only for the sick, and *dal-roti* should not be condemned as a food for the poor.

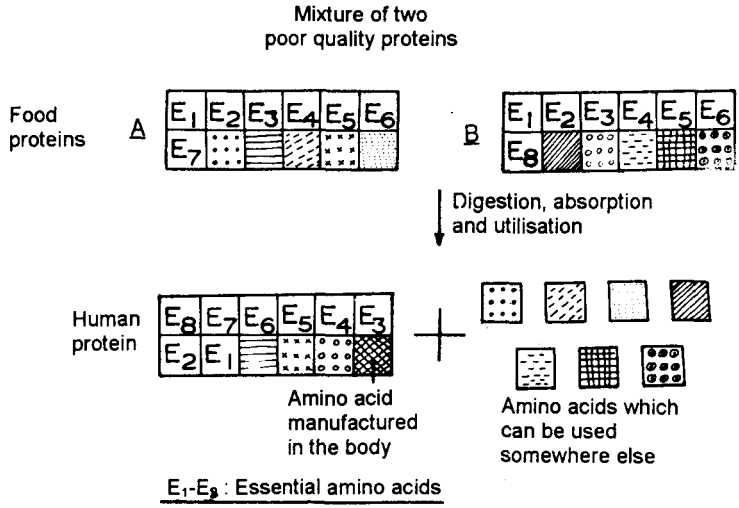

Fig.18: A properly selected mixture of poor quality proteins can function as a good quality protein. In the hypothetical example illustrated here, we have a mixture of two poor quality proteins, A and B. Protein A lacks the essential amino acid E8, while protein B lacks E7. However, the mixture provides the full assortment of essential amino acids, and can therefore be utilised like a good quality protein. In practice, a mixture of cereals and pulses provides such a combination.

Fats are concentrated sources of energy. They improve palatability of food. They delay the emptying of the stomach, so that with fatty meals, the interval between meals can be increased without feeling hungry. They also help in absorption of some of the vitamins. And, of course, they serve as fuel. But in spite of these functions, fats have been under fire for more than three decades. The reason is that overconsumption of fats, particularly animal fats, has been found to be associated with high blood pressure and heart disease. Some vegetable fats have, on the other hand, been found to exert a 'protective' influence. The relevant difference between the two categories of fats is that animal fats are 'saturated', while in general, vegetable fats have a high degree of unsaturation. However, decades of research has finally made us rediscover that moderation is the best path. First, we should avoid too much of fat in the diet. Second, the fat in our diet should come from a variety of sources. Some good combinations include an animal fat, like butter or *ghee* and a moderately unsaturated vegetable fat, like mustard or soyabean oil.

To summarise then, proteins are utilised for body building while carbohydrates and fats are used for obtaining energy. The division is, however, arbitrary and not strictly true. Proteins can be burnt down to yield energy, and there is considerable interconversion of nutrients in the body.

Besides the three energy-yielding nutrients, we need water. Indeed, two-thirds of our body is water. We also need vitamins and minerals. Vitamins and minerals do not provide energy but are vital participants in chemical reactions going on in the body. One might say that they are not candles but matchsticks.

Measurement of Food

In order to know whether one is eating the right amount, it is necessary to quantify the food. Though all food is not utilised to provide energy, for convenience all food is

measured in terms of its potential for providing energy. One gramme of carbohydrate provides four calories, and so does one gramme of protein. One gramme of fat provides 9 calories. A man doing moderate amount of physical work needs about 50 calories per kg of his body weight every day. Children, women and sedentary workers need less calories; those engaged in heavy physical work, and pregnant and nursing mothers need more. More calories for more work applies only to physical work. Mental work needs no additional energy because brain uses the same amount of nutrients whether it is idling, or whether it is solving complex mathematical problems.

The general principle for further allocation of calories to different nutrients is simple. Let us take the case of a 60-kg man engaged in moderate physical work, and therefore, needing 3,000 calories. He should have, like all adult men and women, a minimum of about one g/kg body weight protein. That comes to 60 g protein which would provide him 60 x 4 = 240 calories. The remaining 2,760 calories should come from carbohydrates and fats. The proportion of these two components can be varied within wide limits, but usual diets would provide about 300-900 calories from fats and 1,900-2,500 calories from carbohydrates. Besides adequate proteins and a reasonable mixture of carbohydrates and fats, one should take care to include foods which would supply the necessary amounts of vitamins and minerals.

From Chemistry to Kitchen

Let us now see how a housewife can use the knowledge presented above to prepare satisfactory meals for the family. Regarding quantity, it is ordinarily quite acceptable, and perhaps desirable, to leave everyone on his or her own unless it is important to gain or lose weight. Qualitatively, it is preferable if the housewife can provide a cereal and pulse mixture for the two major meals of the day. How to have this mixture twice every day without making the diet

monotonous will test the culinary skills of the cook. In addition, it is desirable to include some milk or milk product. To provide enough of vitamins and minerals, a green vegetable should be available at the two principal meals. It may be a relief as well as a nutritional bonus to have some of these vegetables uncooked. From the scientific angle, potato is not a vegetable; its composition is closer to that of cereals. Also, from the nutritional viewpoint, fruit and uncooked green vegetables are equivalent.

Not Eating Well

It has been estimated that about one-fourth of humanity is undernourished. It has been found that the problem is largely one of quantity. If a family is able to afford enough of the locally available and acceptable foods, quality generally takes care of itself. The worst sufferers from food shortage are growing children. Undernourished children are weak and fall repeatedly sick. Illness makes them still more undernourished. Thus a vicious circle is established. If the affected child does not succumb to one of the episodes of sickness, it grows up without realising its full physical and mental potential. Marginal malnutrition in adults may not produce serious handicaps, but probably does tell on the general well-being and capacity for physical work.

The other side of the coin is equally bad. Eating more than one's requirements leads to overweight. Besides looking ugly and being less agile, an obese individual is also more prone to heart disease, high blood pressure, diabetes, joint pains, biliary stones, and many other diseases. The basic cause of overweight is energy intake in excess of expenditure (Fig. 19). Therefore, the treatment also basically is reducing the food intake and increasing the energy expenditure (through exercise). Energy intake can be reduced somewhat conveniently by cutting down on high calorie foods, like fried foods, nuts, chocolate, cake and sweets. To fill the belly while keeping the meal light, one

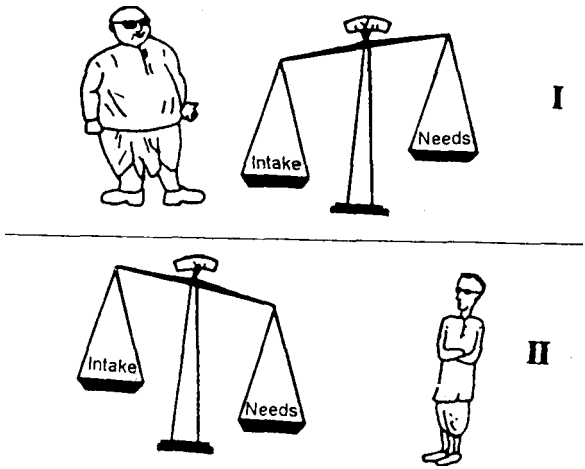

Fig.19: Weight control is essentially a problem of balancing one's food requirements against the intake. If one of them exceeds the other, the result is abnormal body weight.

can eat unlimited quantities of raw vegetables and fruits, which provide almost no calories. Further, it has been found that if the same daily calorie intake is distributed into a larger number of meals, it helps in reducing weight. Preventing over weight in children is even more important because once the foundations have been laid wrong, there remains a life-long tendency to put on weight. The ways of preventing and correcting obesity, viz. less food and more work, are available to all. But not many possess the necessary will power.

7

PROCESSING OF FOOD

Man does not live by bread alone, but can certainly live by bread. Bread and all else that we eat bears little resemblance to the flesh and food which it is expected to form. However, if we go into the chemical composition of food and our tissues, it is found that the basic units constituting both are same. Therefore, what our body does is to first

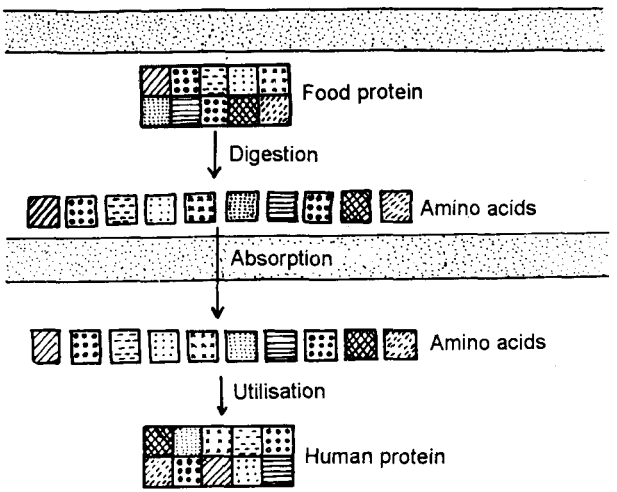

Fig.20: Digestion, absorption and utilisation. Here the three processes have been illustrated with protein. They are broadly similar for other foodstuffs. During digestion, the food is broken down into simpler products. Then it is taken away from the lumen of the intestine into the bloodstream (absorption, *see also* Fig. 24). The absorbed products are *utilised* as building material, as illustrated here, or as fuel (Fig. 17).

break food down into its basic components. This is spoken of as 'digestion'. These components are then transferred to the bloodstream. This process is called 'absorption'. Since blood travels to all parts of the body, these basic constituents reach every cell. They are picked up and utilised in accordance with the needs of the body (Fig. 20).

The process of digestion and absorption takes place in the alimentary canal (Fig. 21). Alimentary canal is a 9-metre long tube extending from the lips to the anus. The processes can be understood by following a morsel of food during the course of its journey through this tube.

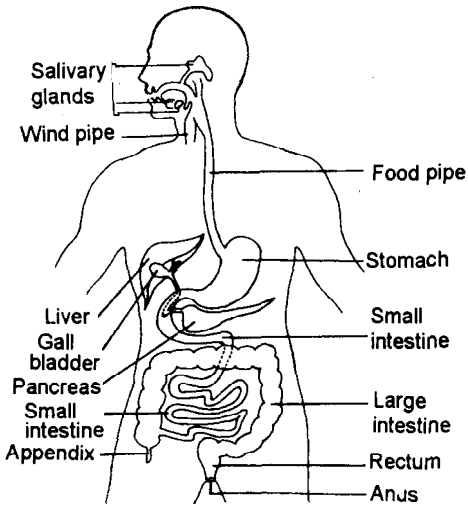

Fig.21: The alimentary canal.

Mouth: The journey is considered well begun if it starts with a thorough cutting and tearing of the morsel at the entrance. The process of chewing converts the food into fine particles. Chewing is required for:

- Reducing the food to small bits which can be conveniently swallowed.
- Breaking the indigestible cell walls of plant cells, so that the digestible contents of the cells can be exposed

to digestive juices.

- Increasing the surface area over which digestive juices can act.
- Allowing time for saliva to act.
- Providing satisfaction from food.

While the food is being tossed around in the mouth it also mixes with a watery secretion* called 'saliva'. Saliva is secreted by a set of three pairs of glands situated in and near the mouth. Saliva not only helps make a decent bolus in the mouth, it also inaugurates the process of digestion. It contains an enzyme** called 'amylase' which breaks down the starch in food into maltose. Because of the relatively short stay of the food in the mouth, the digestion of starch is quantitatively not very significant. But, it is important because starch is tasteless while maltose is sweet. That is why food becomes sweeter after being chewn in the mouth for some time. From personal experience we all know that the secretion of saliva is induced not only by the presence of food in the mouth and chewing, but also by mere sight, smell or even thought of food, specially tasty food.

The stay of food in the mouth is terminated by a gentle twist of the tongue which pushes the food to the back of the mouth. After that the food is swallowed rapidly without our conscious will or knowledge. Swallowing involves a series of complicated steps taking place in quick succession. These steps are aimed at preventing the food from entering the airways till it enters the food-pipe or the oesophagus (Fig. 22). Occasionally something may go wrong with the smooth and precisely timed steps in

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* Secretion is a useful substance discharged by the cells of the body.

** Enzymes are substances, relatively minute quantities of which can increase the rate of chemical reaction. The enzymes themselves do not undergo any change in the process. In the present example, what amylase does in minutes, would not happen even in days if starch were just put in water at body temperature.

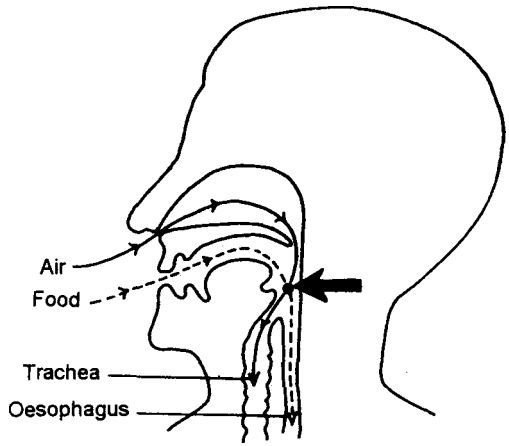

Fig.22: At the inlet, the food passage (mouth) lies below the air passage (nose). But in the throat, the food-pipe (oesophagus) lies behind the wind pipe (trachea). Hence, a criss-crossing of the food and air passages is inevitable (heavy arrow). During swallowing, a number of mechanisms guide the food to the food-pipe, and prevent it from slipping forward into the wind pipe. One of these mechanisms is the rising of the trachea, which can be verified by placing a finger tip on the Adam's apple and then swallowing some saliva. Solid arrows show the path taken by air breathed in; broken arrows show the path taken by food.

swallowing, and food may slip towards the air passage. In that case, coughing comes to our rescue and forcefully chases the food out of the air passages. In an unconscious person, swallowing may not be perfect, and cough reflex may be depressed. Therefore, it is dangerous to force water or tea down the throat of an unconscious person in an attempt to bring him round. The drink may enter his air passages and kill him.

Oesophagus: The stay of food in the oesophagus is very brief. The very presence of food in the oesophagus initiates gentle waves of contraction which push the bolus towards the stomach. At the junction of the oesophagus and stomach, there is a zone of high resistance. A momentary let up in the resistance allows the food to enter the stomach. This

resistance is useful in preventing the acidic contents of the stomach from entering the oesophagus. The lining of the oesophagus is not built to stand acid, and is prone to get inflamed if it comes in contact with the acid. This inflammation gives rise to the symptom of 'heartburn'. This may occur occasionally when something goes wrong with the high resistance zone at the lower end of oesophagus.

Stomach: Stomach is a highly distensible organ. When empty, it is the size of a fist and lies almost completely hidden behind the ribs of the left side. But at the end of a heavy meal, it may bulge to the size of a football and reach below the navel, which indicates the capacity of the stomach to store considerable quantity of food. This capacity confers on us the convenience of taking meals at long intervals of time even though the body needs a continuous supply of nutrients.

The food in the stomach is homogenised by the gentle mixing waves and is also subjected to the action of an acidic juice. Besides having an acid (hydrochloric acid), the juice also contains an enzyme called 'pepsin' which splits proteins into smaller units called 'peptides'. The acid is important because pepsin can act only in an acidic medium.

We have seen that as more and more food enters the stomach, it stretches itself and gastric juice issues forth from the walls of the stomach. How does the stomach know when to secrete juice, when to stretch or shrink, when to merely mix the food gently, and when to forcefully push it forth? Well, these activities are initiated and terminated at right moments by the co-ordinating mechanisms of the body—the nerves and hormones. The principal nerve responsible is the vagus nerve. Increase in activity of the vagus nerve initiates the flow of gastric juice in anticipation of the arrival of the food in the stomach, i.e. when a meal has merely been planned, thought of, seen, smelt or chewn. The vagus nerve also helps continue secretion of the juice, when the food has reached the

stomach. When the food enters the stomach, there is also a chemical (hormonal) mechanism which comes into play to augment the flow of gastric juice. The hormone involved is gastrin* which is elaborated by the last portion of the stomach. The secretion of this hormone is stimulated by the presence of food, particularly proteins, in the stomach, and also by the activity of the vagus nerve. Thus, all the mechanisms for production of gastric juice are active when the juice is really required. When food is no longer present in the stomach, and more food is not expected, the juice would not be necessary, and the mechanisms responsible for secretion are switched off. Gastric secretion is inhibited not merely by withdrawal of stimuli for its continuation. Entry of food into the small intestine releases another set of hormones which actively inhibit gastric secretion. These hormones are the same which increase the secretion of the juice which acts on the food in the intestines. Thus, Nature economises on the hormones by using the same substances to promote secretion where it is required and to stop it where it is no longer required.

We have seen that gastric juice contains pepsin which can split proteins, and also the acid to activate it. The lining of the stomach also contains proteins. Why don't acid and pepsin erode the lining of the stomach? Many factors appear to save the stomach from the corrosive effects of its own secretions. Firstly, most of the acid and pepsin are secreted only when food is available to be acted upon by them. Therefore, not enough of the digestive juice

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* Hormones are substances released directly into the bloodstream. They circulate all over the body but produce some effects only in selected target organs. It is ironic that gastrin and other gastrointestinal hormones also lose themselves in the general circulation and take a circuitous route only to come and act very near the place where they were produced. For instance, the path taken by gastrin is: last portion of stomach—veins arising from the stomach—right atrium—right ventricle—lungs—left atrium—left ventricle—aorta—arteries supplying the stomach—stomach.

probably comes in prolonged contact with the stomach. Secondly, the lining cells (mucosa) of the stomach seem to have specially tough walls which can resist the acid-pepsin attack. Besides, the cells are so tightly packed that the secretions cannot even sneak in through the crevices between the cells. Thirdly, the lining of the stomach is covered with a layer of 'mucous'—a slimy fluid with a weak capacity to neutralise acid. In the past this layer was considered a vital factor in protecting the stomach. But it has been found that it cannot neutralise much acid, and gastric juice can easily penetrate it. Therefore, it is unlikely that mucous offers much protection against erosion. It appears to act mainly as a lubricant. The major protective factor appears to be the cells themselves. In some abnormal circumstances, however, the digestive juice may eat away a part of the wall, resulting in a peptic ulcer. Peptic ulcer may occur not only in the stomach, but also in the portion of the small intestine immediately adjoining the stomach (the duodenum). The process leading to peptic ulcer may be viewed as an imbalance between acid-pepsin and the mucosal barrier. Either there is too much of acid-pepsin, or an impaired mucosal barrier, or a combination of both. The next question obviously is, what is it that produces this imbalance? Over-activity of any of the factors which induce gastric secretion could be the culprit. In practice, it is usually a combination of many factors, some of which have been crisply stated in the triad: hurry, worry and curry. A patient of peptic ulcer is frequently intelligent, ambitious, high-strung, nervous, worried, and often an introvert. His food is often spicy, and he takes plenty of tea and coffee. He may be a smoker and alcoholic.

The other side of the story is impaired mucosal resistance. This happens with aspirin, alcohol and vinegar. That is why habitual consumption of aspirin to relieve headache can also precipitate peptic ulcer in a susceptible individual. Yet, individual susceptibility differs. There seems to be something inherent in the constitution of some

individuals that makes them secrete more acid and/or have impaired mucosal resistance.

The treatment of peptic ulcer is aimed at neutralising the causative factors. Antacids or some other newer drugs are given to counteract the acid. The latest in the line are drugs which inhibit the production of acid in the stomach. Meals are made bland so that the meal excites minimal secretion of gastric juice although it is not certain how far it helps. Small meals are taken frequently so that some food is always present in the stomach to be acted upon by the juice. Tea and coffee should be excluded from the diet, if possible. If that is not possible, only very weak tea should be taken with milk and sugar. If habituated to smoking and drinking, the patient should try to give them up. Last but not least, the patient should change his attitude to life so that he can take the challenges, failures and disappointments of life lightly.

Acidity is a complaint commonly associated with the stomach and is characterised by sour eructations. Every normal stomach produces acid. But, as we have seen, there exists a high resistance zone at the junction of the esophagus and the stomach which does not normally allow this acid to be belched up. It is only when something goes wrong with this safety valve that acid may be brought up, leading to sour eructations. Avoiding sour foods cannot solve this problem, however. No sour food we eat contains more acid than that produced by the stomach itself. The treatment of acidity is essentially a watered down version of the treatment of peptic ulcer, i.e. small and frequent bland meals, and antacids, if necessary.

Gas is another common complaint associated with the stomach, and many quacks thrive on claims to cure it. The source of gas belched out is usually the air which has been swallowed while eating. Some adults and all infants habitually swallow a lot of air while eating, and then feel like expelling it. Anxious and nervous individuals often swallow a lot more air than is normal. They are also the ones

who worry more about gaseous eructations. The more they worry, the more they belch; and the more they belch, the more they worry. Thus a vicious cycle is set up. Such patients just need to be consoled and reassured.

Small Intestine: The food, after being digested in the stomach, is transferred, bit by bit, from the stomach into the small intestine. Emptying of the stomach begins two or three hours after a meal and is completed during the next couple of hours. Many factors can alter these timings, the most obvious being the total quantity of food taken; the larger the quantity, the longer it stays in the stomach. A factor of practical importance is the quantity of fat present in the food. That fat delays gastric emptying is a fact we frequently make use of when we can anticipate

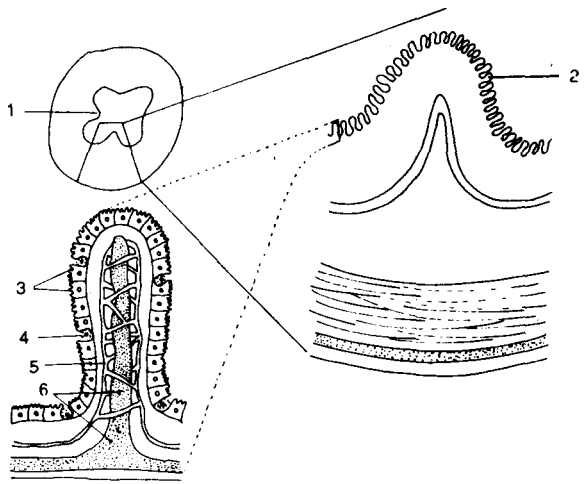

Fig.23: The surface area of small intestine is enormously increased by repeated folding. Increasing degrees of magnification reveal more and more minute folds: *1.* valvulae conniventes; *2.* villi; *3.* microvilli; *4.* goblet cell (Fig.4); *5.* blood vessel; *6.* lymphatic (for fat absorption). The valvulae conniventes, villi and microvilli increase the surface area of the small intestine three-, ten- and twenty-fold respectively, giving a total multiplication of 600-fold.

missing a meal. In that case, we consume more fat at the preceding meal so that the stomach does not empty for a long time and we do not feel hungry.

The first portion of the small intestine which the food enters is called the 'duodenum'. This is an important region because juices from two sources, i.e. pancreas and gall bladder, are discharged into it. Pancreatic juice is a powerful combination containing enzymes for the digestion of carbohydrates, proteins as well as fats. Bile is an essential supplement to the pancreatic enzyme for digestion of fats. Bile emulsifies fats, i.e. it breaks down big fat globules into fine droplets of fat, thereby increasing the surface area on which the enzyme can act.

Discharge of pancreatic and biliary secretions into the intestines is under the control of two hormones: 'secretin' and 'cholecystokinin'. The general principle governing these hormones is also the same as for gastrin: they are there only when required, they do what is needed. The action of pancreatic enzymes completes the digestion of fats only. The final digestion of carbohydrates and proteins is brought about by the small intestine itself, the enzymes for which are located in minute finger-like processes lining the surface cells of intestines. This ensures that as soon as the digestion is complete, the nutrients are already in the intestinal wall, just one step away from absorption into the bloodstream.

Apart from digestion, the main function of the small intestine is absorption. The repeated folds over the surface of the lumen increase the surface area 600-fold (Fig. 23). Thus the structure of the small intestine is eminently suited for its absorptive function. In the process of absorption, digested food is transferred across the wall of the alimentary tract (Fig. 24). Food crosses the wall of the small intestine to enter blood vessels in these walls. Thus blood which arrives at the intestine is enriched with digested food when it leaves. Since blood goes to every organ of the body, the absorbed food also travels to every organ. Hence, food

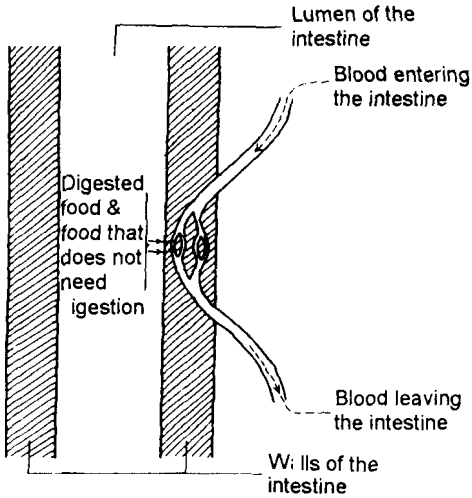
Lumen of the intestine
Blood entering the intestine
Digested food & food that does not need igestion
Blood leaving the intestine
Wi lls of the intestine

Fig.24: During absorption, food enters the blood coming to the intestine and leaves with the blood leaving the intestine. Once absorbed into the bloodstream, food circulates all over the body. It can be used wherever needed.

which, before absorption, belonged to the alimentary tract, belongs to the whole body after absorption. Food which, before absorption, was essentially outside the body, is truly inside the body after absorption (Fig. 25).* The result of absorption is that in the normal individual, by the time the food is ready to enter the large intestine, it contains mainly water, indigestible substances, e.g. cellulose,** and undigested food.

This is the hodgepodge, mixed with bacteria and the debris of intestinal cells shed into the lumen, that is passed on to the large intestine.

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* All foods, except a part of fats, are absorbed into the blood. Most of the fat is absorbed into lymphatics.

** Cellulose forms the cell walls of plant cells. It is a carbohydrate, but cannot be digested by the enzymes present in man. Some animals, like cattle, can digest it. That is why a cow can live on paper while a man cannot.

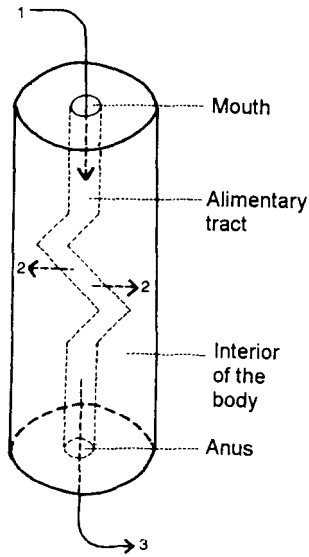

Fig.25: The alimentary canal is open at both ends. The food that is taken through the mouth *(1)* is not really inside the body unless it is absorbed *(2)*. Whatever is not absorbed is eventually lost in faeces *(3)* and is thus effectively outside the body.

Large Intestine (Colon): The large intestine works hard on the rather worthless legacy that it inherits from the small intestine. It extracts from it almost all the water, and some salts and other nutrients. The absorption of water is an important function. Were is not for the assistance of the large intestine, we would pass a large number of lose watery motions every day on one hand, and keep busy drinking a lot of water to make up for the water loss, on the other. Besides water absorption, stay of the residual 'food' in the colon subjects it to the action of germs (bacteria) present there. In the process, some of the indigestible food is 'digested' to provide nourishment to the bacteria. Colonic bacteria and man are not merely in a state of peaceful co-existence; they are mutually beneficial. However, the chemical reactions carried out by

the bacteria produce gases like carbon dioxide, hydrogen and methane. These gases are passed as flatus. Excess flatus is a minor physical inconvenience but a major social embarrassment. While the tendency to form too much flatus is partly hereditary, everyone affected by it can benefit by avoiding beans, milk and any other food found to be consistently associated with flatulence. As a result of the work done by the large intestine, its contents become semi-solid. A part of the contents is voided periodically, usually once a day. The basic pre-requisite for the urge to defecate is the presence of sufficient volume of contents in large intestine so that they can exert the necessary pressure in the terminal portion of the intestine (rectum). The other favourable circumstances are the availability of a proper place and atmosphere for the act, and a relaxed mind. A drink, particularly a warm drink, assists the initiation of the defecation reflex. Long-standing habit might have established some other conditions peculiar to an individual, e.g. smoking or reading, which have also to be fulfilled for easy defecation. Besides, the consistency of the stool should also be soft for a comfortable act.

Considering the above factors, one can visualise the following causes of constipation:

- Insufficient bulk in the large intestine. This can be corrected by consuming some vegetables, fruit and coarse cereals. These items contain considerable quantities of indigestible plant material which imparts bulk to the contents of the large intestine.
- Faulty toilet training and irregular habits.
- Excessive concern with the bowels which does not let the mind relax.
- Insufficient water intake, making the stool hard.

To these causes may be added one more, which is, paradoxically enough, frequent purging. A constipated person is usually obsessed with his bowels. Failure to pass motion for a day prompts him to take a laxative. The laxative empties a long segment of the colon—much longer

than emptied by a normal act of defecation. The result is that the colon does not fill up sufficiently to cause an urge to defecate the next day. This convinces the individual all the more that he is constipated, and he again resorts to a laxative, which overempties the colon. Thus a vicious circle is established which can be broken by not bothering about the stool for a day or two. This would provide enough time for the colon to fill up and eventually establish a natural reflex.

Another common disease of the intestines is diarrhoea, which is more troublesome and more serious than constipation. Diarrhoea is usually infective in nature, and may be caused by a wide variety of organisms. Some of these infections are susceptible to drugs, while others are not. Be that as it may, the body is able to fight many of the diarrhoeal infections without the aid of any drug. The most important part of the treatment of diarrhoea, therefore, is not drugs. Rather, it is the prompt and appropriate replacement of the heavy loss of water and salts in the stools. This is particularly important in children where even a small loss forms a substantial fraction of the total salt and water content of the body.

We started our journey with the food entering the mouth. Now that we have reached the other end, hardly anything of the food is left. It has been all badly battered to bits and taken into the bloodstream in a systematic, assembly-line fashion. This is an important service rendered by the alimentary tract. Like a faithful servant, the alimentary tract also shares the joys and sorrows of the individual. Therefore, it is only proper not to stuff it with too much food, or abuse it with disagreeable foods.

Table: 7.1

Region	*Juice*	*Enzyme*	*Enzyme acts on*	*Enzyme action produces*
Mouth	Saliva	Amylase	Starch	Maltose
Stomach	Gastric juice	Pepsin	Proteins	Protein fragments
Duodenum	Pancreatic juice	Amylase	Starch	Maltose
"	"	Trypsin	Proteins & protein fragments	Small protein fragments
"	"	Chymotrypsin	"	"
"	"	Carboxypeptidase	"	Small protein fragments and amino acids
"	"	Lipase*	Fat	Fatty acids and glycerol
Small intestine**	—	Disaccharidases	Maltose	Glucose and similar substances
			Lactose+ and sucrose++	
	—	Aminopeptidase	Small protein fragments	Very small protein fragments and amino acids
	—	Dipeptidase	2-amino acid fragments	Amino acids

* For effective digestion of fats, bile is also required.

** Small intestinal enzymes are located on the surface of the cells of the intestinal wall. They are not secreted into the intestinal juice.

+Lactose is the sugar naturally present in milk.

++ Sucrose is cane sugar.

Table 7.2

Secretion

Juice	*Stimulated by*	*Inhibited by*	*Mechanism of stimulation/ inhibition*
Gastric:	Thought, sight, smell or taste of food.	Empty stomach.	Stimulated by vagus nerve and gastrin.
	Presence of food in the stomach.	Anger; food entering the duodenum.	Inhibited by secretin and cholecystokinin.
Pancreatic:	Presence of acid and food in the duodenum.	Absence of stimulating factors.	Stimulated by secretin and cholecystokinin.
Bile:	Presence of fats in the duodenum.	Absence of stimulating factor.	Contraction of gall bladder stimulated by cholecystokinin.

8

KIDNEYS: THE FASCINATING FILTERS

Kidneys are often described as bean shaped; on the other hand, a popular variety of beans is called kidney beans. We have two kidneys situated in the abdomen, nearer the back than the front. They form urine continuously, and conduct it via the ureters to the urinary bladder (Fig. 26).

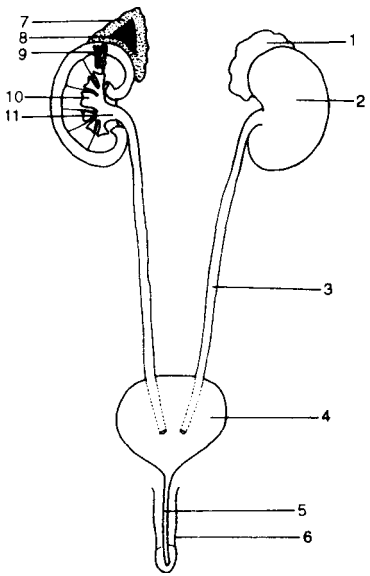

Fig.26: The excretory system of the male. The adrenal glands have also been shown, although they are a part of the endocrine system. The right kidney and adrenal have been cut open to show some structural details: *1.* adrenal gland; *2.* kidney; *3.* ureter; *4.* urinary bladder; *5.* urethra; *6.* penis; *7.* adrenal cortex; *8.* adrenal medulla; *9.* nephron; *10.* calyx; *11.* pelvis of the kidney.

The bladder has considerable capacity for storing urine. When its contents start approaching its storage limit, we feel an urge to pass urine. Provided that the circumstances are appropriate, we give vent to the urge; otherwise we suppress it till a suitable opportunity presents itself. The urine passes from the bladder to the exterior through a narrow tube called 'urethra'. The urethra is about 4 cm long in women. In men, it traverses the entire length of the penis, and is therefore about 20 cm long. Some old men lose part of their control over the bladder, and feel like passing urine rather frequently. This happens because of the enlargement of the prostate gland which surrounds the lower parts of the urethra in men.

Structure of the Kidney

Each kidney is made up of about a million long narrow tube-like structures called 'nephrons'. A nephron is the structural and functional unit of a kidney. The urine formed by a kidney is the sum total of the urine formed by its nephrons. Each nephron is about 5 cm long, but appears shorter because it is extensively folded up at the two convoluted tubules (Fig. 27). The total length of the 2 million nephrons that we possess is, thus, about 100 km, i.e. more than the distance between Delhi and Mathura. The diameter of the different segments of the nephron is 10-60 μ.*

A nephron essentially consists of a receptacle (Bowman's capsule) enclosing a bunch of capillaries (glomerulus) like a closed fist. The receptacle leads to a long tubule. The terminal ends of the tubules from different nephrons start converging and coalescing into common tubes, till finally they form just one tube, the ureter. The glomerulus and Bowman's capsule form one functional entity. They *filter* the blood. The tubules alter the volumes and composition of the filtered fluid.

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* $1\ \mu = \frac{1}{1{,}000}$ millimetre $= \frac{1}{1{,}000{,}000}$ metre.

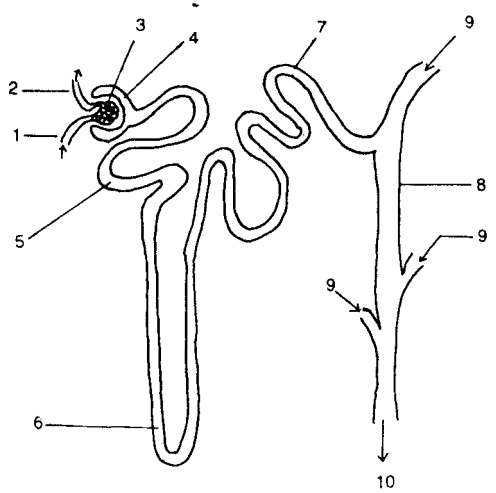

Fig.27: Schematic representation of a nephron: *1.* afferent arteriole; *2.* efferent arteriole; *3.* glomerulus; *4.* Bowman's capsule; *5.* proximal convoluted tubule; *6.* loop of Henle; *7.* distal convoluted tubule; *8.* collecting duct; *9.* collecting ducts from other nephrons; *10.* to calyx.

Filtration

To understand the process of filtration, it is necessary to have a close look at the structures involved (Fig. 28). The glomerular capillaries are fed blood by a blood vessel called the 'afferent arteriole', and are drained by a narrower blood vessel called the 'efferent arteriole'. By virtue of this arrangement, the pressure in glomerular capillaries is higher than that in any other capillary bed in the body. The pressure also happens to be considerably higher than that in the lumen of the Bowman's capsule. Since fluids move from a higher pressure to a lower pressure, it is possible for fluids to escape from the glomerular capillaries into the Bowman's capsule, provided the intervening membranes have pores to allow the transfer. If the filtration surface is viewed with an electron microscope, we can resolve it into three layers. One layer is formed by the cells forming the wall of the capillaries. This layer shows punched out holes,

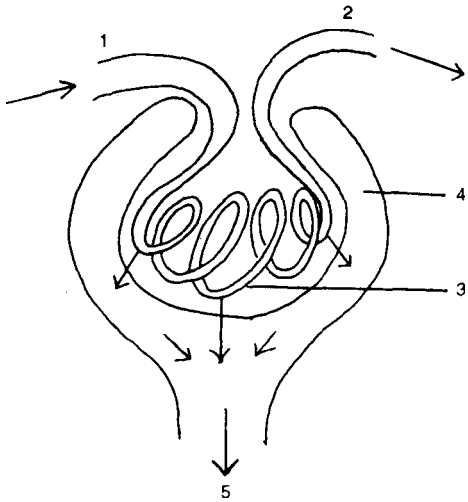

Fig.28: The glomerulus: *1.* afferent arteriole; *2.* efferent arteriole; *3.* capillaries constituting the glomerulus; *4.* Bowman's capsule; *5.* the fluid filtered into the Bowman's capsule passing on to the proximal convoluted tubule.

about 400-1000 Å ** in diameter. The next layer is formed by a membrane which has holes only about 100 Å in diameter. The last layer consists of cells which have projections. The projections of contiguous cells fit into one another like a jigsaw puzzle, leaving only small gaps in between. These gaps allow molecules no bigger than about 30 Å to pass through them with ease. In short, the filtration surface may be visualised as a series of successively finer sieves. The final sieve has pores only around 30 Å wide. But it is well to keep in mind that it is an indiscriminate sieve. It allows every molecule smaller than 30 Å to pass through it. That is why, the fluid formed as a result of filtration (filtrate) contains not only urea, which it is desirable to discard, but also a great deal of water, glucose,

** $1\ A^{\circ} = \frac{1}{10{,}000}\ \mu = \frac{1}{10{,}000{,}000{,}000}$ metre.

amino acids and salts, which it is not desirable to discard. In short, the filtrate resembles the plasma (Chapter 3) except that it does not contain the plasma proteins.

Tubular Function

The amount of filtrate formed every day would fill more than ten buckets. If all this were to be eliminated as urine, one can imagine the amount of water one would have to drink to replace the loss. Further, as mentioned earlier, the filtrate also has numerous other substances which deserve to be conserved. These problems are looked after by the tubules. Before the filtrate becomes urine, the tubules remove from it about 99 per cent of water and almost all the essential solids. Removal of these substances from the lumen of the tubules and returning them to the bloodstream is called 'reabsorption'. The tubules not only reabsorb substances, they also transfer some substances from the bloodstream to the lumen of tubules. The process is called 'secretion'. The most important substance secreted is acid. In the course of chemical reactions going on in the body, many acids are produced. By secreting acids, the kidneys help in maintaining the acidity of the body fluids constant.

Thus the final urine excreted is the result of three basic processes: filtration, reabsorption and secretion.

The amount and composition of the filtrate formed is rather constant at about 120 ml every minute. Of this, about 85 per cent of water is always absorbed in a normal kidney in the initial portions of the tubule. Glucose and amino acids, being nutrients, are always welcome; so they are also reabsorbed right in the beginning of the tubule. There is, however, a limit to which glucose can be reabsorbed. Normally that limit is never exceeded, and therefore, glucose is completely reabsorbed. But in diabetes, the blood glucose concentration is high. Therefore, the concentration of glucose in the filtrate is also high. If the concentration exceeds the capacity of the tubules to reabsorb

glucose, glucose spills over in the urine. That is why the urine of a diabetic is sweet, and sometimes the ants that collect around the urine give a clue to the diagnosis. The glucose in the urine has, in order to stay dissolved, to carry at least a minimal quantity of water with it. That is why a diabetic passes large volumes of urine. To make up for the excessive water loss, he drinks a lot of water. Further, to compensate for the food lost in the form of glucose in the urine, the diabetic eats a lot. Excessive eating (polyphagia), excessive drinking (polydipsia) and too much of urine (polyuria) are the three cardinal symptoms of diabetes.

The extent to which more water and various other substances are reabsorbed or secreted varies with the requirements of the body. Requirements of water and salts, and production of acids, would depend upon various factors, such as their intake, production, and loss through other routes. The reabsorption and secretion of these substances in the kidneys is so adjusted that the various cells of the body are bathed in a fluid which is relatively constant in composition. We see an illustration of these facts in everyday life. For instance, in summers we lose considerable water through sweating. To compensate for it, we would lose less water in urine. Accordingly, the urine is smaller in volume and consequently more yellow in colour, indicating that the yellow coloured solids in the urine have been dissolved in a smaller volume of water. If we take exercise in the hot sun and produce additional sweating while restricting our water intake, the urine becomes minimal and very concentrated indeed. Just the opposite phenomenon occurs in winter if we take a couple of glasses of water. How the kidneys know when to do what is again the marvel of the communication systems of the body, viz. hormones and nerves. The kidneys, of course, have to be responsive to the communications they receive from these channels. We shall discuss briefly only two of the major mechanisms involved.

There is a tiny part of the brain called the 'hypothalamus'.

Within the hypothalamus is a still tinier part which is very sensitive to the concentration of water in the blood. As soon as the blood becomes just a bit more concentrated than normal, this part of the hypothalamus detects the change before any other cells of the body realise that something has gone wrong. It responds to this change by producing a chemical substance called 'antidiuretic hormone' (ADH). This substance travels in the bloodstream to the kidneys and increases the reabsorption of water so that the blood gets a little thinner. In this way, by regulating the release of ADH, this part of the brain keeps the body water constant.

An important mechanism for regulation of salt in the body is located in an organ lying just over the kidney, and therefore called the 'adrenal gland'. The fact that it lies close to the kidney is only a coincidence. It functions in just as circuitous a manner as it would if it had been in the neck or the leg. It is sensitive to the salt content of the blood. As soon as the salt (sodium) concentration becomes just a little less than normal, it releases into the bloodstream a substance called 'aldosterone'. Aldosterone, upon reaching the kidneys, induces them to reabsorb more sodium, thereby tending to restore the sodium concentration of body fluids.*

There are some chemical substances which can trick the body mechanisms into producing more urine even when, physiologically speaking, the body need not do so. Such substances are called 'diuretics'. The diuretic effect of alcohol and tea is a common experience. Alcohol does so by inhibiting ADH secretion. The caffeine, present in tea, acts directly

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* Although blood is only a part of the body fluids, the concentration in body fluids and the concentration in blood can be used interchangeably in the present discussion. The reason is that blood and the other fluid compartments of the body have constant exchange going on amongst them. Therefore, a change in one reflects that in other compartments also.

on the kidneys to reduce the reabsorption of water. Some diuretic drugs form a part of the treatment of certain diseases.

Abnormal Kidneys

Part of the renal tissue may get damaged by various types of insults. Some disease processes affect the kidneys directly and exclusively. Some others affect blood vessels in general, those of the kidneys included. If the blood supply is affected, renal function is affected. This is to be expected since the entire function of kidneys depends upon adequate perfusion with blood. Generalised diseases which involve the kidneys include high blood pressure and diabetes.

In diseases of the kidneys, it is well to keep in mind that a nephron once lost does not repair itself back to normal. We have to make do throughout life with the nephron population we are born with. But like other vital organs, kidneys also have considerable physiological reserve. One can safely carry on all routine functions with just one kidney instead of two.

Kidneys can get damaged by various agents, such as germs, stones, chemicals, etc. The damage may be sudden and severe in its impact, giving rise to the so-called 'acute renal failure'. More commonly, however, the damage progresses slowly, giving rise to 'chronic renal failure'. Damage to the glomerular filter may allow precious plasma proteins to escape in the urine. Damage to the tubules may impair reabsorption of water and salts, resulting in their excessive loss in the urine. Impairment of the acid-secreting mechanism may lead to accumulation of acids in the body. Urea, the chief breakdown product of proteins, fails to get excreted adequately, and therefore its concentration in the blood increases. The treatment of these disorders is aimed at making up the excessive losses and reducing the load on the kidneys. When the damage to kidneys reaches a point where these supportive measures cannot sustain life, the only alternatives left are 'renal

transplantation' or 'dialysis' (artificial kidney).

Renal Transplanation: Transplants of the kidney have been relatively more successful than those of the heart and other organs. Transplants taken from identical twins are the most successful. But such a kidney is only rarely available. In that case, the kidney of any close blood relative or any other donor can be used after appropriate testing for compatibility. Cadaver kidneys taken from individuals who have died less than one hour earlier have also been used successfully.

Dialysis (artificial kidney): The so-called artificial kidney is based on the simple principle that substances tend to move from a higher concentration to a lower concentration. But when actually put into practice, it takes a very sophisticated and expensive form. The machine used consists essentially of a membrane which allows the passage of water and other small molecules, but not of plasma proteins or blood cells. The patient's blood is brought to one side of the membrane and a specially designed solution (dialysing fluid) is brought to the other side of the membrane. The dialysing fluid has all the small molecules in the same concentration as *normal* plasma *except* that the substances, which a patient with renal disease accumulates, are absent. Therefore, when the blood and the fluid are present on the two sides of the membrane, the accumulated substances pass from the blood into the dialysing fluid.

Artificial kidney is useful in acute as well as chronic renal failure. In acute renal failure, it is required periodically for only a few weeks to tide over the period of crisis. During this period, the kidneys recover sufficiently from the acute trauma to take over their normal function. On the other hand, a patient of chronic renal failure has to get dialysis carried out for twelve hours every three or four days for the remainder of his life. The cost of long-term dialysis in terms of men and material is so prohibitive that no country in the world can provide this facility to all those

who may benefit from it.

Prevention of Renal Disease

Prevention is usually simpler and cheaper than cure. Probably it is nowhere more true than in the case of kidneys. Most of the diseases of the kidneys are either due to germs, or due to formation of stones. Germs cannot grow in plain water; they need food. Therefore, they grow much better in concentrated urine than in dilute urine. Stones can also form only if some salts crystallise as solid particles, which is possible only in a concentrated solution. Therefore, dilute urine is a safe urine. To make the urine dilute, all one needs to do is to take plenty of water. This suggestion assumes special importance in the summers of the tropics, when the mercury touches 45° C and profuse sweating is common. Then it takes a very conscious effort to drink sufficient water frequently enough. But it is certainly worth the trouble.

Sips of water is what it takes
To keep your kidneys shipshape.

9

BODY DEFENCES

We are a part of a delicately balanced environment. All living beings depend upon one another, directly or indirectly. Nevertheless, survival is not necessarily a result of peaceful co-existence. Very often it is the result of an exercise for exclusive existence. Human beings can possibly be killed by tigers and snakes. But the mighty enemies of man, really to be dreaded, are the tiny germs or microbes, visible only with the help of a microscope. They are present all around us. There are millions of them in every drop of water that we drink, in every whiff of air that we breathe. In spite of living in such a hostile environment, man, as a species, has survived for million of years; and as an individual, every man can hope to live the biblical three score and ten years. Medicine has very little to do with this miracle. Scientific medicine as we know it today, has been in existence for an infinitesimally small fraction of human history. Further, even at its best, medicine only assists the built-in defence mechanisms of the body which are responsible for this miracle. Unfortunate individuals, whose defence mechanisms are impaired, do not live long in spite of best medical aid.

In a broad sense, every part of the body is also a part of the defence mechanisms of the body to the extent that it contributes to the well-being of the organism. But some organs involved in defence in a rather direct fashion may be mentioned. The eyes, ears or nose give us a clue about an approaching enemy, the muscles enable us to run away from, or put up a fight with a predator. Some mechanisms

prevent germs from entering the body, e.g. the skin covering almost the whole body, and the hair and sticky fluid present in the nose. Some others kill the microbes as soon as they enter the body, e.g. acid in the stomach, or the tears in the eyes. Some of the most effective weapons of the body are, however, not so obvious. The present discussion will be centred chiefly around them.

MONONUCLEAR PHAGOCYTIC SYSTEM (MPS) OR RETICULO-ENDOTHELIAL SYSTEM (RES)

This system is a family of ubiquitous cells which have specialised in dealing with germs and forcing particles by eating them up. That is why these cells are called 'phagocytes' (*phagein*, 'to eat'; *cyte*, 'cell'). They are present in all tissues but are particularly concentrated in liver, spleen, and bone marrow. Monocytes in the blood are the circulating counterparts of these cells. Any microbe or undesirable substance entering the body is sure to run into some of the cells of the MPS. Then cells engulf the invader. Once

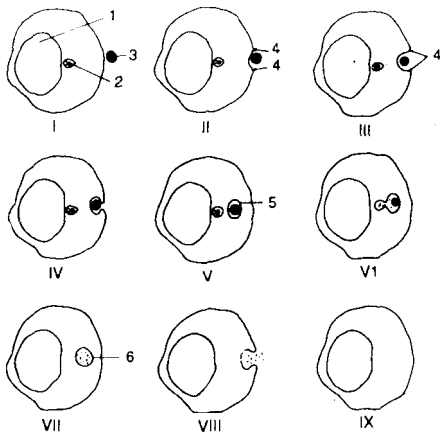

Fig.29: Stages in phagocytosis I to IX: *1.* nucelus; 2. lysosome; *3.* particle to be ingested; *4.* cellular processes (pseudopodia); *5.* vacuole containing ingested particle; *6.* digested particle.

within the cell, the invader is in a spherical space called 'vacuole' (Fig. 29). The vacuole fuses with lysosomes (Chapter 2) present in the cells. The lysosomal enzymes digest the invader. As in the digestive tract, some of the waste remains of the invader are expelled from the cell.

It is apparent that phagocytosis is an important mechanism for combating many diverse invasions. But the process is non-specific, and is devoid of memory, i.e. an encounter with an invader does not make the body better equipped to handle a subsequent encounter with the same organism. The significance of the process lies in that it is present even at birth, and does not require prior exposure to the invader.

SPECIFIC ACQUIRED IMMUNE MECHANISMS

These are the more fascinating, and also more complicated defence mechanisms of the body, still far from being completely understood. They afford specific protection against specific germs, and are endowed with memory.

Like phagocytosis, acquired immune mechanisms are also a true defence system; they are never the aggressor. The germs first have to get into the body to activate the immune system. In spite of this handicap, the system works with such rapidity and ferocity that the aggressor is generally overwhelmed. At the first encounter with the aggressor, the response of the immune system is rather slow and weak. But at subsequent encounters with the same or similar germs, the response is generally very rapid and vigorous. Specific acquired immunity can be broadly categorised into two groups: humoral immunity and cellular immunity.

The type of response selected by the body depends upon the nature of the aggressor: the body seems to know which weapon will be most effective for whom. The central organisation of both types of responses is in the lymphoid organs of the body. Lymphoid organs are

factories for the production of lymphocytes. These organs include principally bone marrow, thymus, lymph, nodes, spleen and some 'patches' in the wall of the small intestine. Corresponding roughly to the two responses, there are two types of lymphocytes—B lymphocytes concerned with humoral immunity, and T lymphocytes concerned with cellular immunity.

1. Humoral Immunity

Humoral immunity comes into play in response to invading germs, as well as some harmful chemical substances. The harmful chemical substances (toxins) may be those which are produced by the invading germs. The main feature of the response is the production of proteins (antibodies) which circulate in the bloodstream and neutralise or help eliminate the invading agent.

What triggers antibody production?

Antibody production is usually triggered by a protein called the 'antigen'. The antigen may be, and usually is, only a small part of the invading agent. If this part is identified, separated and introduced into the bloodstream, it alone also triggers the antibody response. If the antigenic component of a number of germs is the same, antibodies evoked in response to all of them will be the same. Obviously, therefore, infection by any one of them will afford protection against others also. On the other hand, some organisms, such as the flu viruses have such a large variety of antigens that antibodies against one are ineffective against another. Therefore, getting flu once does not insure us against future attacks.

How are antibodies produced?

Upon entry into the body, the antigen first comes into contact with macrophages (phagocytes) in the tissues (Fig. 30). The reaction of the antigen with the macrophage, in some mysterious way, renders it fit for recognition. After

the antigen has been 'presented' by the macrophages and appropriately processed by lymphocytes, a select group of B lymphocytes proliferate and differentiate into antibody forming cells (plasma cells). Plasma cells start manufacturing antibodies specific for the antigen 'presented'.

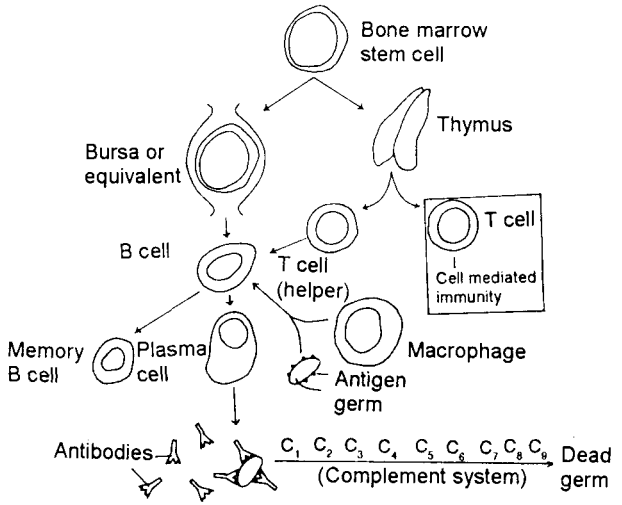

Fig.30: Humoral immunity. When exposed to an antigen, it requires the cooperation of the macrophages and helper T cells to transform appropriate B cells into antibody-forming plasma cells. An additional product is a memory B cell, which would result in a prompt and intense antibody response to any subsequent exposure to the same antigen.

Theories which have sought to explain the synthesis of specific antibodies can be grouped into 'instructive' and 'selective' theories. Instructive theories postulate that all plasma cells are alike. It is the antigen that directs the plasma cells to manufacture a specific protein (antibody). Selective theories, originally proposed by Burnet, on the other hand, assume that there are as many types of B cells as the antigens. The presence of the antigen, according to selective theories, only triggers the proliferation of appropriate cells and expression of their potentialities. Available

evidence is overwhelmingly in favour of selective theories.

What are antibodies?
Antibodies are proteins belonging to a class called 'gamma globulins' or immunoglobulins. Most of them circulate in the blood as a fraction of the plasma proteins. But one type, called IgA, is present in secretions like those of the mouth, intestines, nose and eyes. IgA molecules keep these surfaces coated so that germs cannot enter our body through delicate surfaces.

How do antibodies work?
If the antigen is a toxic substance, the antibody binds it. The complex is harmless and can circulate without doing us any harm. If the antigen is part of a germ, binding of the antibody to the antigenic site is not the end. The binding sets into motion a train of events which results in death of the germs. The events involve another set of substances circulating in the blood, collectively called the 'complement' because these substances complete the job of the antibody. After the germ-antibody complex has been joined by the complement, the germ is killed by phagocytosis.

2. Cellular Immunity
Humoral immunity is manifested in the form of circulating antibodies, and is, therefore, most effective against germs and poisons which circulate in the blood. However, there are many germs which take shelter within the cells of the body. For such organisms, there is another variant of the immune response in the body. Here also, the macrophage presents the antigen to T lymphocytes (Fig. 31). The result of this contact is to convert tranquil T cells into 'killer' T cells, technically called sensitied T cells. Sensitised cells not only deal with the organism directly, but also indirectly by stimulating the proliferation of similarly sensitised T cells all over the body. Besides, this penchant for multiplying their own tribe, sensitised T cells neither forgive nor forget

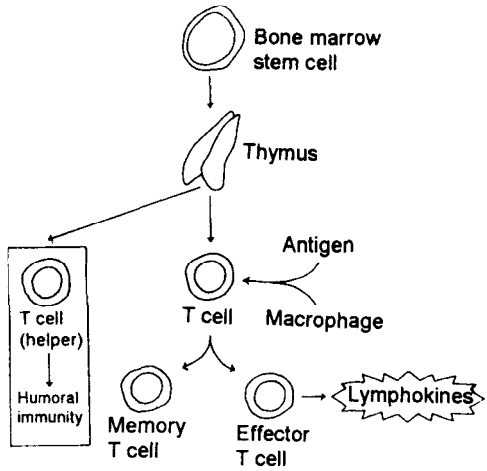

Fig.31: Cellular immunity. The antigen is 'processed' by the macrophages, and then presented to the T cells.

the enemy. Because of their good memory, they swing into action promptly whenever the same organism invades the body again.

The direct effect of sensitised T lymphocytes on the invasion is two-fold:

- They hunt for the cells which have been invaded by the germs and kill them. The ideal way to go about things, perhaps, would be to kill only the germs, leaving the cells intact and healthy. But that does not seem to be possible. The best way under the circumstances, therefore, is to resort to a radical measure: kill the cell to get rid of the germs within it; if the cell dies, the germs also die. It is a measure akin to amputating a limb with an incurable cancer.
- They produce a family of soluble chemical substances, collectively called 'lymphokines'. Without going into the individual effects of each recognised lymphokine, one might say that their overall effect is to attract the different white cells of the blood which help in fighting the infection, to prevent proliferation of germs, to

stimulate the production of more similarly sensitised lymphocytes, and to increase the resistance of host cells to some types of germs, and by producing lymphokines sensitised T lymphocytes make life miserable for the invading organism.

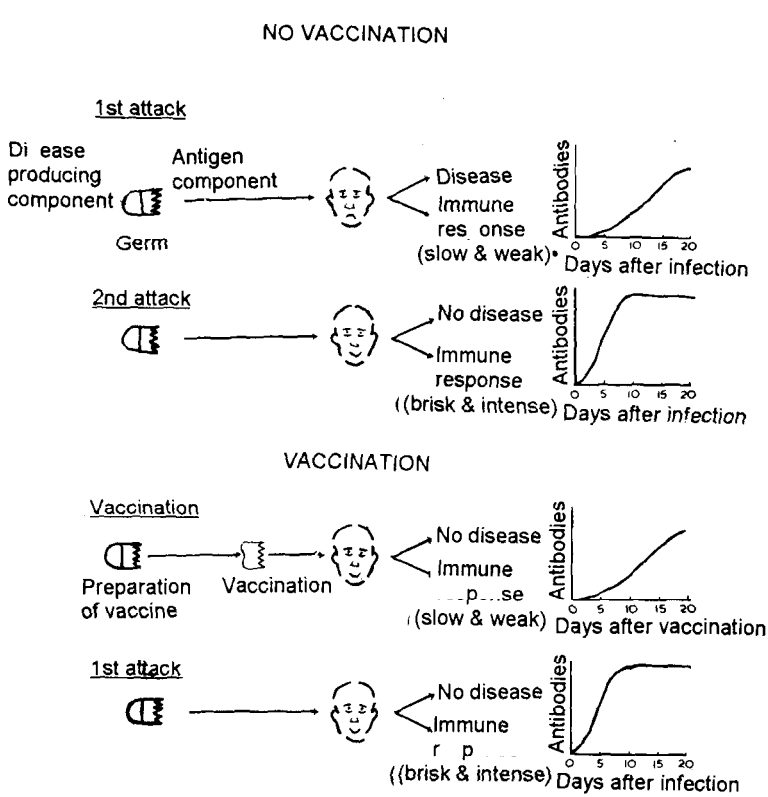

Fig.32: Principles of immunisation. The antibody response to the first attack by a germ is slow and weak, and hence, disease symptoms appear. But the second attack is promptly aborted by the brisk and intense antibody response. Vaccination makes use of these facts. The first attack is simulated by vaccination which, however, does not produce the disease because only the antigenic component of the germ has been injected. The first real attack by the germ is now treated in the same way as the second attack in an un-vaccinated individual, resulting in protection from disease.

Immunisation

A major limitation of the immune mechanism of the body described above is that they come into play only after the noxious agent has entered the body. The response to the first attack is relatively slow and weak, and therefore, the agent often does some harm before being vanquished. If we can artificially mimic the first attack in such a way that it evokes the immune response without producing symptoms of the disease, the first real attack will be treated by the body as a second attack. This is what we generally do when we immunise an individual (Fig. 32). In order to produce the first disease-free attack, the germ is killed or suitably modified and then injected in a measured quantity. The major problem of preparing a vaccine, therefore, is to find the right procedure for the specific germ in question. The procedure has to be such that the germ loses its capacity to induce disease while retaining its capacity to evoke an immune response. Immunisation is the single most cost-effective tool of preventive medicine.

There are several schedules of immunisation which differ in minor details; the one based on the National Immunisation Programme schedule is given below:*

Before birth	
During pregnancy	Two doses of tetanus toxoid, four to six weeks apart; the second dose latest by 36th week of pregnancy
After birth	
At birth	BCG (to prevent tuberculosis) OPV (oral polio vaccine)

* Based on Bir Singh & Anil Goswami's booklet in Hindi on *Immunisation*, published in 1998 by the National Service Scheme Cell, Centre for Community Medicine, AIIMS, New Delhi.

6 weeks	OPV
	DPT (diphtheria, pertussis and tetanus vaccine)
10 weeks	OPV
	DPT
14 weeks	OPV
	DPT
9-12 months	Measles vaccine
16-24 months	OPV
	DPT
5-6 years	DT (diphtheria and tetanus vaccine)
10 years	TT (tetanus toxoid)
15 years	TT

It is desirbale to continue TT every three to five years throughout life because one never knows when an injury might create a risk for tetanus.

Some other vaccines have not been provided for in the National Immunisation Programme but are available in the country. These are:

Hepatitis vaccine: The vaccine may be had at any age. Optimally, three doses are required: the interval between the first and second dose being one month, and that between the second and third being six months.

Like BCG and OPV, the hepatitis vaccine may also be given soon after birth. For sustained immunity, one dose of the vaccine should be repeated every three years.

Oral typhoid vaccine: This vaccine is available in the form of capsules under the brand name 'Typhoral'. Three doses (one capsule each) of the vaccine may be had at one-day interval each by anyone above the age of six years. For example, if the first dose is taken on a Monday, the second dose should be taken on Wednesday and the third on Friday during the same week. For sustained immunity, one dose of the vaccine should be repeated every three years.

Allergy

Allergy is an instance where too much of a good thing proves bad. Sometimes the body treats ordinary harmless substances as harmful and reacts to them by a volatile and exaggerated immunological response. The result is an allergic reaction. An allergic reaction can take many forms. Respiratory distress (as in asthma), running of the nose, or a skin rash are common manifestations. Immediate death, as happens in a few cases after a pencillin injection, is not so common. An allergy may occur in response not only to drugs, but also to ordinary foods like banana or tomato, to pollen grains, to cosmetics, etc. The substance, the introduction of which is followed by the allergic reaction, is called the 'allergen'. Besides treatment of an isolated attack of allergy, it is also important that the allergen be avoided in future. Difficulties arise mainly on two scores:

- The allergen may not be known.
- It may not be always possible to avoid an allergen, e.g. pollen grains.

The first difficulty may be resolved sometimes by eliminating all the suspected allergens from the life of the victim and then introducing them cautiously one by one. It goes without saying that the substance identified as the allergen should be avoided ever after. This method is particularly applicable if the allergen happens to be a food or a cosmetic.

The second difficulty can be overcome to some extent by desensitisation, which essentially involves regularly repeated injections of the allergen, starting with a very low dose and increasing it gradually. Desensitisation is a time-consuming and laborious process. A nasal filter may be useful for those who are allergic to inhaled particles, like dust and pollen.

10

ENDOCRINES: THE POSTAL SYSTEM OF COMMUNICATION AND CO-ORDINATION

The human body is comparable to a civilised society. Just as individual members of the society specialise in different tasks, different parts of the body also perform a specific function. However, as in the society, all parts are interdependent, and work towards a common goal—the welfare of the whole. It is easy to visualise the contribution of the farmer, the weaver and the scavenger to the existence of the society, just as the contribution of the heart, lungs or kidneys to our survival can be easily grasped. But one should not forget in the process the organiser, be it the village headman or the massive machinery of the government. The organiser may himself do nothing, but he keeps track of what everybody is doing and sees to it that everybody's activities are directed towards general good. In other words, the organiser is in to and fro communication with the parts. On the basis of the intelligence gained from them, it guides them into co-ordinated activity. In man and other complex living organisms, the function of the organiser is performed by two systems—a set of chemical messengers called 'hormones', and the nervous system. Hormones are slow in their action, and may be compared with the postal system. The much faster nervous system is comparable to the telegraphic system, and will be dealt with in the subsequent chapters.

Hormones

Hormones are chemical substances manufactured by

organs called endocrine glands (*endon*, 'within'; *krinein*, 'to separate') or ductless glands. The nomenclature signifies the fact that these glands pour their produce (or what they have 'separated') directly into the bloodstream, without it having to pass through a duct. In contrast, glands like salivary glands guide their secretions to their destination by means of tubes, called 'ducts'. That is why such glands are sometimes called 'exocrine glands' (*exo*, 'outside'). Though hormones travel all over the body in the bloodstream, many of them act only in selected organs (called 'target organs'). The specific affinity of a hormone for a target organ is explained by the premise that receptors for the hormone are restricted to the target organs. The target organ of a hormone may be close to its site of production, or may be far away from it.

Small quantities of hormones bring about major shifts in metabolism, resulting in pronounced effects on structure and function. The timing and quantity of a hormone released is finely controlled. The endocrine gland usually has mechanisms to monitor the requirements of the body for the hormone it produces. In other words, there is a link from the target organ to the endocrine gland through some end result of the hormone's action, often a metabolic product. The endocrine gland is affected by this metabolite in such a way that when there is a deficit of the metabolite produced by the effect of the hormone, the endocrine gland becomes more active, thereby correcting the metabolic picture. In other words, the target communicates with the endocrine gland through a code. The endocrine gland decodes the message; at times it integrates messages from different sources, and translates its 'decision' in the form of the rate of release of its hormone. The hormone now carries the message to the target organ where it is decoded in terms of its metabolic effects. The metabolic effects are such as to result in a better co-ordination of bodily activities.

The way hormones have been detected one by one

makes interesting reading. The first hormone was discovered at the beginning of 20th century. At the University College, London, William Maddock Bayliss and Ernest Henry Starling were trying to study the control of secretion of pancreatic juice. They separated a segment of the duodenum from the rest of the intestine and severed its nerve supply, so that the intestinal segment was connected to the rest of the body only through its blood supply. They found that if acid was placed in the segment of the duodenum, pancreatic juice was poured into it. Since the link between this segment and the rest of the body was only through the bloodstream, it was inferred that perhaps acid in the duodenum results in some secretion into the bloodstream which reaches the pancreas and provokes it to discharge its juice. The really critical experiment was, however, performed on the afternoon of 16 January, 1902. A piece of the duodenum was ground up and its acid extract was injected into the bloodstream. This also resulted in pancreatic secretion, while injection of acid alone did not produce the pancreatic secretion. This conclusively demonstrated that the duodenum can supply a substance which upon getting into the bloodstream stimulates pancreatic secretion. Bayliss and Starling called the afternoon of the experiment 'a great afternoon' which it truly was. They tried to further refine the active principle from the duodenum, and christened it 'secretin' (*secrenere*, 'to separate'). They also coined the term 'hormone' (*hormaein*, 'to excite')* for this general class of substances, which shows that they had an intuition that many more substances of a similar nature would be discovered. Their hope has been amply borne out by the large family of hormones known today.

All hormones have not been discovered in this fashion,

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* All hormones do not excite the way secretin excites the pancreas; in fact, many of them inhibit. But by common usage the term 'hormone' has come to be applied to all such substances.

however. The clue to many of them was obtained from patients who had an excess or deficiency of one of the hormones. Correction of the symptoms by removal of a gland, or injection of its extract, suggested a hormonal basis for the symptoms. The nature of the symptoms gave a clue to the function of the hormone in the normal individual. The experiments of Nature on man were then deliberately repeated on animals. Appearance of similar symptoms in the animals lent further support to the conclusions. It is largely by such procedures that the foundations of endocrinology were laid.

Endocrine Glands of the Body

The time-honoured, better-understood endocrine glands of the body are the following (Fig. 33).

- Thyroid
- Pancreas
- Adrenals
- Gonads
- Parathyroids
- Pituitary

Here we shall discuss briefly only the first two because diseases affecting them are relatively common.

Thyroid

Thyroid gland is situated in the neck in front of the wind pipe. It manufactures two closely related hormones: tri-iodothyronine (T_3) and tetraiodothyronine (T_4), also called thyroxine. As indicated by their names, both these hormones contain iodine. Their actions on the body are qualitatively the same; it is only that T_3 acts much faster but for a shorter period of time than T_4.

Thyroid hormones fan the metabolic processes of the body. Almost all chemical reactions are speeded up, and the heat production by the body increases. These effects are manifested by an increase in the body temperature and heart rate, and a general increase in the tempo of physical

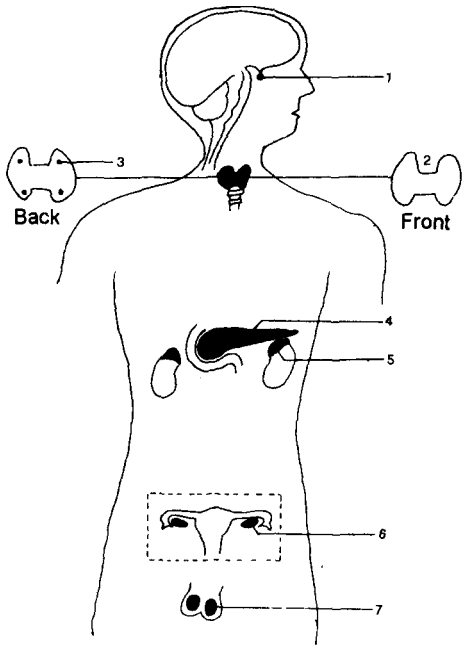

Fig.33: The endocrine glands of the body: *1.* pituitary; *2.* thyroid; *3.* parathyroid; *4.* pancreas; *5.* adrenals; *6.* ovaries (in females); *7.* testes (in males).

and mental activity.

With this background, it is not difficult to understand the effect of diminished thyroid activity (hypothyroidism: *hypo*, 'under') on the body. The effect is more marked in childhood, since rapid growth and development require optimal thyroid activity. Since the brain is the organ that develops the fastest in early childhood, it is seriously affected by deficient thyroid function. Hypothyroidism in childhood gives rise to a condition called 'cretinism'. A child born with this malady may be heavier than the average normal newborn. He feeds less, sleeps more, and has a large tongue. The large tongue may make his breathing noisy, his voice hoarse, and may give him choking spells. He appears uninteresting and uninterest-

ed, and is often constipated. His extremities may feel cold to touch. He is slow to learn, as shown by the age at which he begins to sit or stand. As he grows up, his handicap becomes more apparent, and he develops into a physically and mentally retarded individual. However, if the disease is detected within the first few months of life, the child can be made to develop properly by daily administration of adequate doses of the thyroid hormone. If the treatment is started within the first three months, about half the children attain intelligence in the normal range. If the disease is detected late, the physical development can still be restored to essentially normal level by the thyroid hormone, but there is no way to make up for the damage already inflicted on the brain. In view of the great importance of mental function, it need hardly be emphasised that the attention of a doctor should be sought promptly if an infant is found to be cool, callous or constipated.

If hypothyroidism develops in adulthood, the effects are not as serious as in a child. The individual becomes physically and mentally sluggish, his voice becomes hoarse, he gains weight and gets constipated. He finds it difficult to tolerate cold; even in summers he may insist on sleeping indoors with a blanket on. On examination, his resting heart rate and body temperature are found to be low. This combination of features is called 'myxoedema'. All symptoms of hypothyroidism in the adult can be reversed by thyroid hormone. However, once the patient feels fit, there is a temptation to stop the medication. It should be realised that in this case, the thyroid hormone is only trying to make up for the deficiency of a substance that is normally produced every day in the body. Therefore its requirement is lifelong. Withdrawal of the thyroid hormone results in return of all the symptoms. In view of the above discussion, it will not be surprising if some of the readers who feel sluggish off and on (and everybody does, sometime or the other) get tempted to take some thyroid pills for extra zest

and vigour. However, this step is not to be taken lightly and needs careful laboratory tests and consideration by a doctor. Too much of a good thing can also be bad, as will be evident from the symptoms of the disease in which the thyroid gland becomes overactive (hyperthyroidism; *hyper*, 'above'). The unfortunate victim of this condition feels very hot; he can brave the winters without woollens, but feels miserable in summers. He may have diarrhoea, tremulous hands, and loss of weight in spite of a voracious appetite. On examination, his resting heart rate and body temperature are raised. For ill-understood reasons, some of these patients have markedly protruding eyes. Hyperthyroidism may be treated by some drugs, or by surgical removal of the thyroid gland.

Goitre: Goitre is an enlargement of the thyroid gland. It manifests itself as a swelling in the neck. A goitre may be associated with increased, normal or decreased activity of the thyroid gland. The phenomenon of an enlarged thyroid showing more activity than a normal sized one is quite understandable. The association of a goitre with normal or decreased function may be explained as follows. If the thyroid gland is primarily less active than normal, the body tries to attain normalcy by enlarging the thyroid. The enlarged thyroid may be able to perform normal functions, or may still remain less active in spite of becoming large. In India, a goitre of this variety is highly prevalent in hilly areas of the sub-Himalayan belt. In these regions the soil is deficient in iodine. Therefore, the plants grown there are also iodine-poor. Since iodine is an essential component of thyroid hormones, in a situation of iodine scarcity a normal sized thyroid gland is unable to trap enough iodine to manufacture the normal quantity of hormones. The body tries to correct the defect by stimulating the thyroid to grow bigger and often this enlarged thyroid is able to manufacture the normal quantity of hormone in spite of iodine deficiency. That is why many otherwise normal people can be seen going round in these

regions with large swellings in their necks. For cosmetic reasons, and to avoid the possibility of a cretin being born to them, it is desirable that the population should be normal in every respect. This can be achieved by supplying some iodine in the diet. The surest way to make iodine universally available in the area is to mix 0.01 per cent of the iodine containing salt, potassium iodide, with table salt, and to ban the sale of plain table salt in the region. Although the severest forms of iodine deficiency are found in the sub-Himalayan belt, some degree of iodine deficiency occurs in all parts of India and several other parts of the world. Therefore the Government of India launched the universal salt iodisation programme in 1986. The target has been achieved in some states of the country, and is likely to be achieved in the rest in the near future.

Pancreas

The pancreas has already been introduced as a part of the digestive system. The same organ also manufactures two important hormones. The endocrine department of the pancreas is scattered throughout its substance in the form of tiny islands. The islands have been named 'islets of Langerhans' to honour the memory of Langerhans who was the first to observe them under the microscope when he was just twenty-two. The islets have two major types of cells called A and B. The A cells secrete the hormone 'glucagon', while the B cells secrete the well-known hormone 'insulin'. In view of its importance, only insulin shall be discussed.

Insulin: The association between diabetes and impaired pancreatic function has been known for very long. But the discovery of the antidiabetic principle from pancreas eluded many able investigators. The credit for the discovery ultimately went to a young surgeon, Frederick Grant Banting, and a medical student, Charles Herbert Best. They named the substance insulin (*insula*, 'island') because it is manufactured in the islets (*islet*, 'island').

Insulin affects significantly the manner in which carbohydrates, proteins and fats are utilised in the body. In general, one might say that insulin promotes utilisation of glucose in all possible ways, and also stimulates the synthesis of proteins and fats. As a result of the effect of insulin, more glucose is broken down to provide energy. The utilisation of glucose for synthesis of glycogen and fats is also enhanced by insulin. The manufacture of glucose from protein sources is, on the other hand, depressed by insulin. The net result of the action of insulin, therefore, is to reduce the quantity of glucose in the body, and consequently the concentration of glucose in the blood also falls. Since insulin encourages the utilisation of glucose for producing energy, proteins and fats are spared from being used as fuel. Besides this indirect effect, insulin also has a direct effect of increasing the synthesis of proteins and fats, thereby promoting growth and gain in weight.

The rate of release of insulin into the blood fluctuates many times in a day depending on the requirements of the body at a particular instant. The pancreas seems to assess the insulin requirements of the body from the blood glucose level. Insulin is poured into the blood when the level of glucose rises, and insulin release declines when the level of glucose has fallen to a critical level. This ensures the maintenance of blood glucose level within a narrow range. The mechanism is called into action several times a day, i.e. whenever we eat and whenever we exert ourselves, because while eating adds glucose to the blood, exercise uses up glucose.

Reduction in the quantity of effective insulin gives rise to diabetes mellitus (*diabetes*, 'siphon'; *mellitus*, 'of honey'), commonly called simply 'diabetes'. Deficiency of insulin reduces the quantity of glucose utilised, leading to its accumulation in the body. Hence, the blood glucose level rises, and may rise so much as to exceed the re-absorptive capacity of the kidneys. In that case, glucose spills over in the urine causing the most commonly known symptom of

diabetes, viz. sugary urine. Since the urine contains glucose, the urine also has to have enough water to dissolve it. Therefore, a diabetic passes large quantities of urine, and often has to get up a number of times at night to pass urine. The body compensates for excessive urination by making the patient feel unduly thirsty. On one hand, the patient is unable to utilise enough glucose for getting energy, and on the other, the utilisation of proteins and fats cannot fully compensate for the defect. Therefore, the patient is effectively 'starved in the midst of plenty': he virtually bathes in a sweet solution without being able to use the sugar. That is why loss of weight and excessive appetite are other symptoms of diabetes. In short, a diabetic eats a lot, drinks a lot, passes plenty of sugary urine, and loses weight.

The treatment of a diabetic is based on the interplay of food, exercise and insulin. Food adds glucose to the blood, while exercise and insulin remove it. First, we alter the diet in a manner that it adds glucose to the blood rather slowly. This can be done by reducing the sugar content of food, taking carbohydrate in the form of starchy whole grains as far as possible. Second, we facilitate utilisation of glucose by encouraging physical activity. For many elderly patients with mild diabetes, these two measures are all that is necessary by way of treatment. But some diabetics need additional assistance in the form of insulin. Here the doctor tries to mimic Nature by supplying insulin in situations in which it is normally released in non-diabetics. However, man is not as perfect as Nature. Insulin once injected cannot be switched off; the exact quantity to be supplied in relation to every different meal cannot be accurately predicted, and the number of injections given in a day has to be kept at a minimum.* In view of these limitations, a patient on

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* Insulin has to be given by injection. It cannot be given by mouth because, being a protein, it is digested to amino acids in the

(Contd.)

insulin has to keep his daily diet and exercise constant. If he takes a heavy meal, his insulin will not be enough. Even more serious is the situation if he misses a meal but does not miss the insulin. In that case, the blood glucose level can fall to dangerously low levels. An unaccustomed exertion, associated with the usual dose of insulin but no extra food, can also lead to the same serious consequences by consuming extra glucose.

The above account gives only the most important principles of treatment. The actual treatment requires attention to many minor but important details which are beyond the scope of this book.

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gastrointestinal tract. However, some diabetics can now be treated by oral pills. These pills act by either stimulating the patient's own B cells of the pancreas to release more insulin, or by increasing the utilisation of glucose. Both these groups of drugs require that the patient should have at least some B cell function left. Therefore, pills are usually suitable only for elderly diabetics. Young diabetics are generally devoid of any substantial insulin secretion of their own.

11

NERVOUS SYSTEM: THE TELEGRAPHIC SYSTEM OF COMMUNICATION AND CO-ORDINATION

The present chapter deals with a system of communication which is prompt and can be switched on or off at very short notice. It is this system that makes the mouth water as soon as there is sight, smell or even thought of tasty food, and quickens the heart beat as soon as physical exertion is anticipated. This system is also responsible for all our logical and abstract thinking. The communication of messages in this system is through solid white cord-like structures called 'nerves'. This system is called 'nervous system'. Messages are conveyed along nerves in the form of electrical impulses which seem to jump from one point on the nerve to the next in a systematic manner. The frequency and pattern of impulses seem to form a code which can be decoded by the recipient structures. Not only the rapidity with which the messages are conducted in nerves, but also their coding in a manner somewhat akin to the Morse code, have prompted the comparison with the telegraphic system.

Nerves constitute the peripheral nervous system in contrast to the brain and spinal cord which together constitute the central nervous system. Brain is located inside the hollow of the skull. Spinal cord is housed in the canal that runs through the backbone (vertebral column). All parts of the nervous system are interconnected. In fact, brain continues into the spinal cord, and nerves arise from the brain or the spinal cord (Fig. 34 & 35).

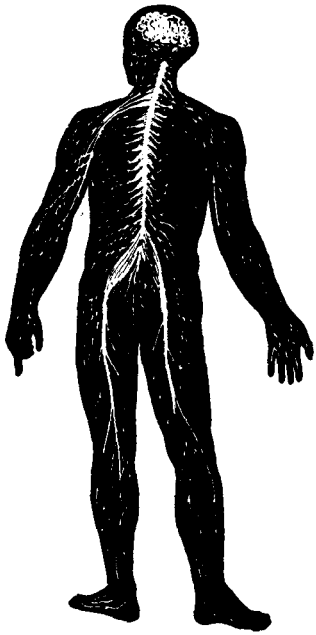

Fig.34: The brain and spinal cord (central nervous system) and spinal nerves (peripheral nervous system). (Reprinted from Miller, M.A., Drakontides, A.B., Leavell, L.C., Kimber-Gray-Stackpole: *Anatomy and Physiology*, 17th edition, 1977, Fig. 9-2, p.200. *Courtesy*: The Macmillan Co., New York, USA.)

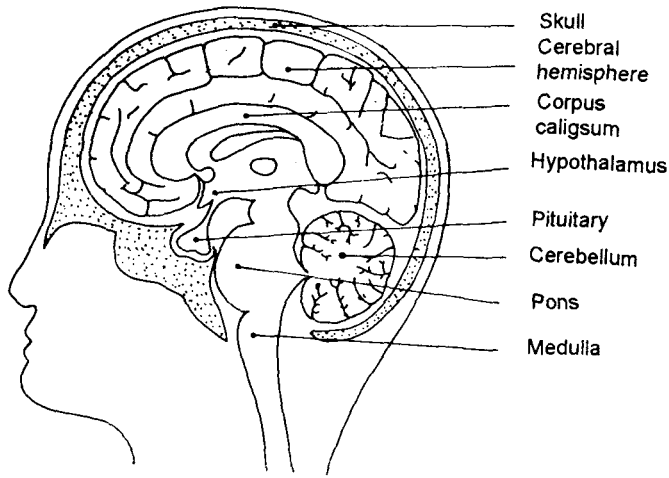

Fig.35: A simplified side view of the human brain, split open along the middle.

Just as the structural unit of the kidneys is a nephron, the structural unit of the nervous system is a neuron (Fig. 36). In order to meet its specialised function, the neuron assumes a characteristic form while still retaining some basic features of a cell. It has a nucleus and cytoplasm, forming the cell body. The cell body has elongated extensions of cytoplasm. Those extensions which are specialised for transmitting messages to the neuron are called 'dendrites', and the extension that transmits messages from the neuron is called an 'axon'. The cell bodies of most neurons are located in the central nervous system.

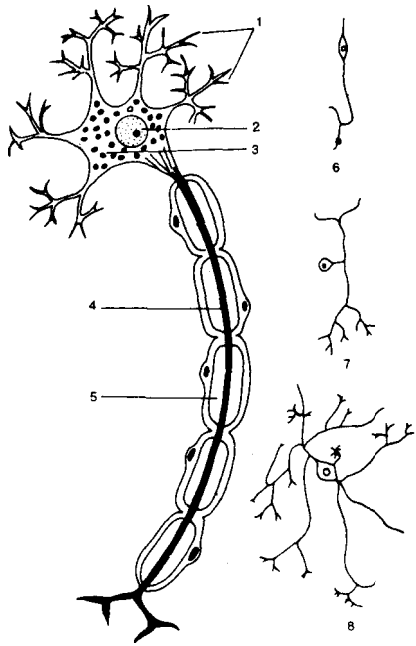

Fig.36: Diagram of the structure of a nerve cell (neuron) showing dendrites *(1)*; nucleus *(2)*; cytoplasm *(3)*; axon *(4)*; and myelin sheath *(5)*. Although a 'typical' neuron is usually drawn as depicted in the detailed diagram on the left, neurons can assume a wide variety of shapes; some such shapes are shown on the right *(6-8)*.

Neurons are interconnected with each other, forming a complex network (Fig. 37). In order to resolve the complexity of neuronal network one might start with simple chains of neurons which accomplish a reflex action. A 'reflex action', or simply, a reflex, is a fundamental function of the

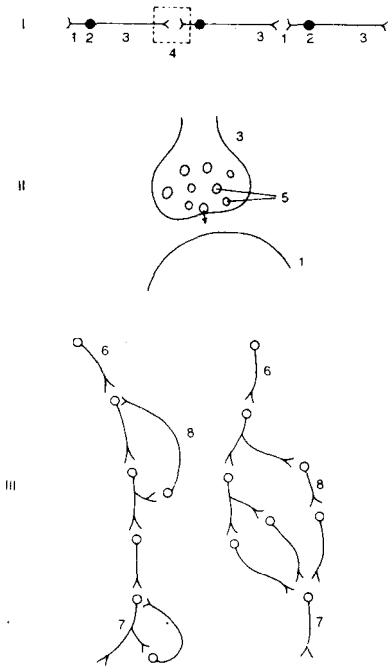

Fig.37: Inter-neuronal communication: I. diagrammatic representation of a chain of three neurons: *1.* dendrites; *2.* cell body; *3.* axon; *4.* synapse (junction between two neurons). (For further simplification, dendrites are also usually omitted as in III.) II. Neurons communicate with each other at synapses by releasing a chemical (neurotransmitter) at the terminal and the axon (*3*). The neurotransmitter is contained in balloon-like sacs called 'vesicles' (*5*). During the process of communication, a small quantity of the neurotransmitter is released in the gap between the axon and the dendrite *(1)* of another neuron. III. Neurons form complex networks, some idea of which may be had from two extremely simple ones depicted here. For simplicity, the dendrites have been omitted. The effect of exciting neuron *6* on the activity of neuron *7* could differ depending on whether neuron *8* is excitatory or inhibitory.

nervous system. Although the term reflex* is used quite commonly, it is pertinent here to describe it rather precisely. Reflex actions are involuntary, inborn and stereotype responses to stimuli mediated by the central nervous system. That a reflex is involuntary implies that it takes place irrespective of will power. No deliberate or conscious action is involved on the part of the individual displaying the reflex action. That a reflex is inborn implies that it does not have to be learnt. That does not mean that all reflexes are present at birth. Many of them appear later without being taught. On the other hand, some reflexes, for instance the suckling reflex, are present at birth but disappear later. Some reflexes, such as micturition and defecation reflexes, are present at birth, but get modified by superimposition of voluntary control that develops later. That a reflex action is stereotype in nature implies that so long as the stimulus is the same, the character of the response is exactly the same on all occasions. Not only is it uniform in a given individual, its pattern is quite similar throughout a species, and quite often, even in many related species. For example, if a finger is pricked with a pin, the invariable response is withdrawal of the hand by flexing (bending) the arm. Every time the finger is pricked, the response is the same. This does not, however, mean that a reflex cannot be modified or extended by learnt behaviour. For example, if a man steps on a piece of burning coal, the reflex response is to jump off the piece, but the subsequent behaviour is voluntary, learnt, and will therefore vary with the nature of the individual and the circumstances involved. He may move the coal aside so that anybody else is unlikely to repeat his experience, or he may pour some water over it with the same motive, or he

* Since reflexes are involuntary, the part of the central nervous system called 'cerebral cortex', which executes voluntary activities, does not mediate reflexes. In other words, reflexes are mediated by levels of central nervous system lower than the cerebral cortex.

may just leave it there and walk on. It is not certain what the reflex response to a slap is, but the learnt response could vary from returning the slap to offering the other cheek.

The chain of neurons that participates in a reflex action is called a 'reflex arc' (Fig. 38). It consists of at least two neurons. One of them (sensory or afferent neuron) conveys the information about the stimulus to the central nervous system. The other (motor or efferent neuron) conveys the message from the central nervous system to the organ (effector organ) which has to respond to the stimulus. There may be one or more neurons (interneurons) interposed between the sensory and motor neurons. The more the interneurons, the more complex would be the processing of the information received by the central nervous system, and correspondingly, the decision or instructions conveyed to the effector organ would also be more complex. The complexity is increased by the fact that all these

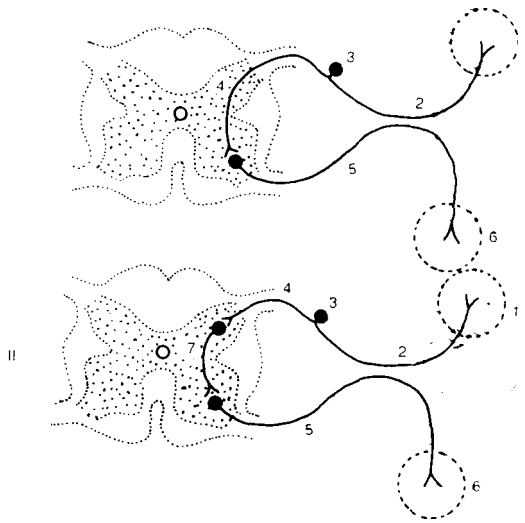

Fig.38: Diagrammatic representation of reflex arcs: I. the simplest reflex arc is made up of just two neurons (monosynaptic reflex arc). II. A reflex arc is made up of three neurons: *1.* receptor; *2.* dendrite of sensory neuron; *3.* cell body; *4.* axon; 5. axon of motor neuron; *6.* effector; *7.* interneuron.

interneurons do not stimulate the neuron(s) they impinge on. Some of them actively inhibit the neuron(s) within their sphere of influence.

A few examples of reflexes have already been cited. Innumerable other reflexes are going on within the body. Only some of them are the type in which the stimulus and the response are both obvious. For example, when the hand is withdrawn in response to a pinprick, both the stimulus and the response are obvious and the 'performer' becomes aware of both within a few moments of the 'performance'. The 'involuntary' component of the act which qualified it as a reflex is that the decision to withdraw the hand is not taken at a conscious level. But in many reflexes, not only the decision regarding the nature of the response, but also the very existence of the stimulus and the response never reach consciousness. For example, the secretion of gastric juice in response to presence of food in the stomach, or the inhibition of gastric juice in response to entry of food in the duodenum are reflexes which take place without the stimulus or the response ever reaching consciousness. Such reflexes control the activities of the heart, respiratory system, urinary tract and reproductive organs. Their operation outside the realm of consciousness saves us the agony of taking care of so many details of the functioning of the body. It would undoubtedly be a big botheration; further, in spite of all our intelligence, we can't be trusted to voluntarily control the tempo of activity of all our internal organs and keep it in tune with the requirements of the body. The division of the nervous system that controls the involuntary activities of the body is called the 'autonomic nervous system'. The afferent limb of the autonomic reflexes may be stimulated by stimuli arising outside the body, for example, heat, cold or a pinprick; or inside the body, such as changes in the glucose, oxygen or acid concentration of blood. The efferent limb of autonomic activities has some unique features, and therefore deserves an elaborate description.

Autonomic Nervous System

Autonomic nervous system is customarily divided into sympathetic and parasympathetic. The efferent nerves of both these divisions are located in the central nervous system, but they do not innervate the organs directly. They communicate their message through another neuron. The junction between the two neurons is called a 'ganglion' (Fig. 39). In general, the post-ganglionic fibre is extremely short in case of the parasympathetic division.

The effects of the sympathetic division are beneficial in an emergency or stressful situation. It is only appropriate

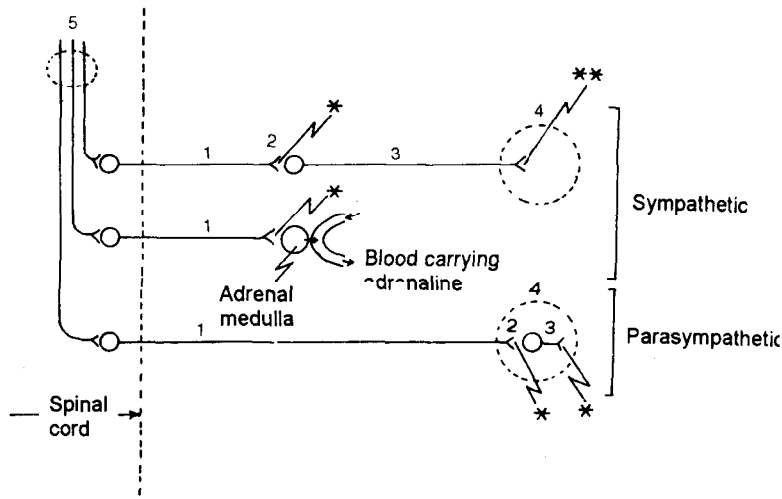

Fig.39: The structural and functional features of sympathetic nerves, adrenal medulla and parasympathetic nerves compared and contrasted. 1. preganglionic neuron; 2. ganglion; 3. postganglionic neuron (notice how short it is in the parasympathetic since the ganglion is in or close to the organ innervated); 4. the organ innervated by sympathetic or parasympathetic nerves; 5. higher influences from the brain affecting autonomic outflow.

* acetylcholine released as neurotransmitter.

** noradrenaline released as neurotransmitter.

Note that the adrenal medulla is a modified sympathetic ganglion. Its cells act like postganglionic neurons, but release adrenaline directly in the bloodstream.

that an arrangement which helps in an emergency is considered 'sympathetic'. On the other hand, in a relaxed state, parasympathetic activity predominates. Parasympathetic effects are generally opposite the sympathetic effects, but they cannot be considered unsympathetic, since they are beneficial in the circumstances in which they occur. Organs innervated by autonomic nerves usually receive both parasympathetic and sympathetic nerves, which modulate their activities in opposite directions. With the above background, it is easy to predict the sympathetic and parasympathetic effects on various organs (Fig. 40). For example, in an emergency, a person may need to run, and that would require vigorous action of the

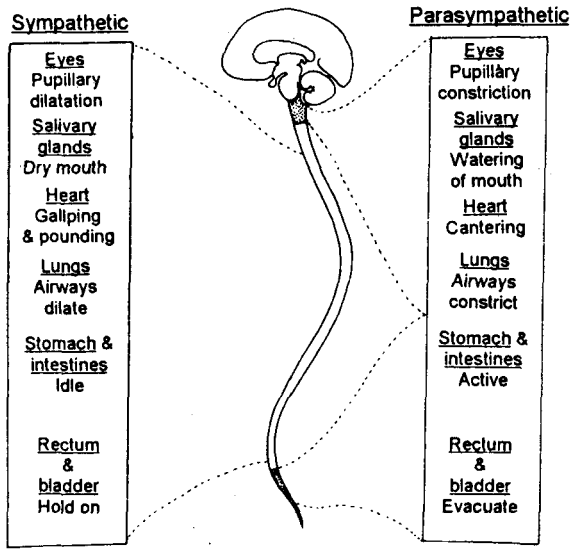

Fig.40: The parasympathetic outflow is from the brain stem and the tail end of the spinal cord (dotted areas). The sympathetic outflow is from a considerable length of the middle of the spinal cord. The effects of sympathetic and parasympathetic activity on some organs of the body have also been shown. Note that they are essentially opposite in character. The sympathetic effects are useful in an emergency, and the parasympathetic effects are desirable when one is at peace.

heart and vigorous breathing. Accordingly, sympathetic nerves increase the rate and pace of contraction of the heart and dilate (open up) the airways. On the other hand, one would like to read only in a relaxed state. Correspondingly the pupils constrict to make near objects clearer as a result of parasympathetic activity; sympathetic stimulation dilates (widens) the pupils.

It would be appropriate to ingest and digest food, defecate or urinate only in a relaxed state. Accordingly, gastrointestinal motility and secretions, and rectal or urinary bladder contractions are stimulated by parasympathetic activity. The sympathetic activity does just the opposite. The remarkable thing is that while parasympathetic stimulates rectum or urinary bladder, it relaxes the sphincter so as to facilitate evacuation, while sympathetic has opposite effects (Fig. 41). Thus the actions are in terms of functional utility, rather than contraction or relaxation.

One might ask why there need be two sets of nerves for every organ. For example, what is the need for having parasympathetic nerves to slow down the heart, and

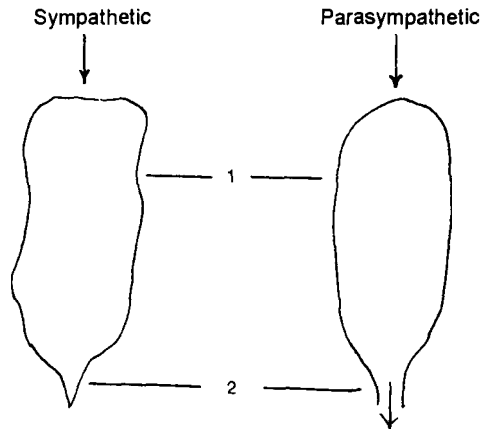

Fig.41: Effect of autonomic nerves on hollow organs like the urinary bladder or rectum. Sympathetic nerves relax the organ (*1*), but close the sphincter at the opening, (2) tightly thereby permitting storage. Parasympathetic nerves make the organ contract but relax the opening, thereby facilitating evacuation.

sympathetic nerves to quicken the heart; for instance, if there were only parasympathetic nerves, their stimulation would slow down the heart. Thus both functions, viz. slowing and quickening, could be served by only one set of nerves. To understand the advantage of two sets of nerves, a useful analogy is that of automobiles, all of which have both accelerators and brakes. Although it is possible to slow down a vehicle by discontinuing the use of the accelerator, more effective slowing can be achieved by using the brake in addition.

At any given moment in the relaxed state, one will either only eat or read or defecate, and therefore, pronounced parasympathetic effects are usually confined to the region involved, although the predominant tone may be parasympathetic throughout the body. In contrast, in an emergency, sympathetic effects are observed throughout the body, because they all cooperate and co-ordinate to equip the body better to face the situation. For instance, a rise in heart rate and force of contraction of the heart, facilitation of rapid and forceful breathing, suspension of gastrointestinal and urogenital activity, and elevation of blood glucose are all required simultaneously to fight any type of emergency better. Not only is there an outpouring of sympathetic nerve impulses throughout the body, there is also simultaneous release of adrenal medullary hormones, adrenaline and noradrenaline (Chapter 12). The overall effects of adrenal medullary hormones and sympathetic activity are similar, because postganglionic sympathetic nerve fibres also release noradrenaline. The 'sympathoadrenal reaction', as the combined reaction is called, seems to have evolved in animals who have to frequently fight an enemy or catch a prey for their very survival. Therefore the reaction was christened the 'fight, flight or fright reaction' by the eminent physiologist, Walter Cannon, at Harvard Medical School in the early 20th century. The full-blown reaction is seldom required in the 'civilised' man, but continues to be observed as a hangover from our

evolutionary past. Further, civilised behaviour requires that we suppress many aspects of this reaction deliberately. For instance, we often cannot spank or run away from the source of our anger. The result is that our sympathoadrenal reaction mainly serves to raise our heart rate, blood pressure and blood sugar, without these changes being put to any use. If such reactions are all too frequent in a person he may develop a persistently high blood pressure. Such a person would have his autonomic balance permanently tilted towards the sympathetic. In contrast, yogis and others with calm and meditative personalities have a parasympathetic tilt in their autonomic balance. They are less prone to develop the diseases of modern civilisation like high blood pressure or heart disease.

Reflexes and autonomic functions are relatively basic activities of the nervous system, which are subject to control by higher levels of the central nervous system. In addition, the higher centres of nervous system are also the structural basis of intelligence, memory, discrimination, abstract thinking and such other intellectual functions. To a limited extent one might say that the more highly evolved an animal is, the more elaborate is the higher control superimposed on basic neural functions. Among men also, people who cultivate a stronger voluntary control over basic biologic urges, like hunger, thirst, anger or sex, and those who have better developed intellectual functions, are considered more civilised. Like everything refined, the higher neural functions are also the more delicate ones. They are the first ones to be knocked out by any substance that numbs the nervous system. One such substance is alcohol.

Contrary to popular impression, alcohol is not a stimulant for the brain. It depresses brain functions, the most susceptible being the higher functions like intelligence and discrimination. The result is that the restraint that normally keeps basic and baser instincts under check is lifted, and the person becomes elated, garrulous and rowdy. Thus the

apparent stimulation is the result of inhibition of an inhibitory influence. With still larger quantities of alcohol, consciousness is also impaired, and finally the most basic and most resistant functions such as cardiac and respiratory centres are also depressed. When that happens, the individual dies. Only rarely does a person drink himself to death, although it is possible to do so.

12

MUSCLES AND JOINTS: A MOVING STORY

Lungs replenish the oxygen consumed by the body and get rid of the carbon dioxide produced by it. But in order to do so, they have to be expanded and squeezed alternately. The heart pumps blood by filling and emptying alternately. The stomach sends the food to the intestines by pushing it further. We lift a weight, or walk from one place to another, by using our limbs. One phenomenon that is common to all these activities is motion, and the structure that brings about motion is called 'muscle'. The fundamental property of muscle tissue is contraction. At molecular level, all contractile tissues have at least two proteins—actin and myosin—somewhat erroneously called 'contractile proteins'. The nomenclature is misleading because the proteins do not contract, but merely get rearranged every time the muscle contracts or relaxes.

Muscles are conveniently categorised into three varieties—cardiac, smooth and skeletal. Cardiac muscle is the muscle of the heart. Its function is a part of the working of the heart (Chapter 6). Smooth muscle is the muscle of internal organs, such as the stomach, intestines, urinary bladder, blood vessels or uterus. Cardiac muscle and all smooth muscles share one common feature, i.e. their action is not under the control of will power. That is why they are spoken of as involuntary muscles. They have a certain degree of inherent activity, which is further modulated by autonomic nerves (Chapter 11). In contrast, the third variety of muscles, the skeletal muscles, are under the control of will power, and are therefore spoken of as

'voluntary muscles'. It is these muscles that we employ to throw a ball or to climb the stairs as and when we like. Their nerve supply is also somewhat differently organised. Moreover, voluntary muscles have no inherent activity. Their activity is entirely dependent on their nerve supply. When the nerve supplying a voluntary muscle is activated, the muscle contracts. As soon as the nerve activity ceases, the muscle relaxes.

Skeletal muscles are the muscles that one ordinarily thinks of when talking about muscles. Biceps, triceps and all the other muscles that give our body its contours are skeletal muscles. Besides big muscles that enable us to run and dance, muscles of the face that reveal our feelings are also skeletal muscles, as are also the muscles of breathing. All these muscles are called 'skeletal' because they are attached to bones (the skeleton) at their end. In fact, muscles taper into tough whitish cord-like structures called 'tendons' which, in turn, are attached to bones. One thick

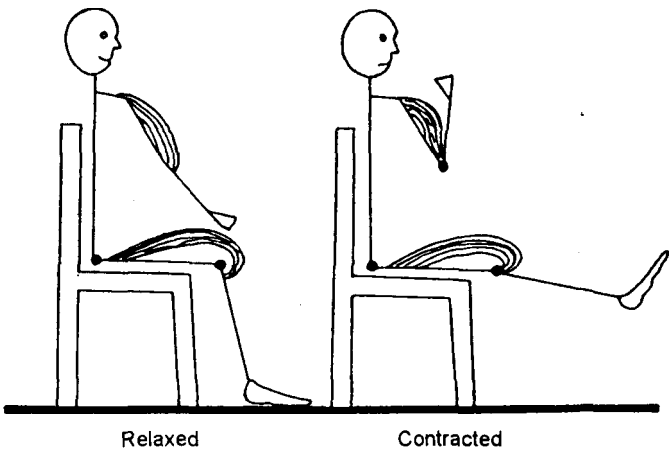

Fig.42: Skeletal muscles are attached to bones and always cross a joint. The position of the attachments and the nature of the joint determine the type of movement brought about by activity of the muscle.

round tendon which we are all familiar with is at the ankle near the heel. The two ends of a skeletal muscle are always attached to two different bones. In other words, a skeletal muscle always crosses a joint between two bones. The positions of the bony attachments determine the nature of the movement a muscle brings about when it contracts (Fig. 42).

The equivalent of a cell in a muscle is a muscle fibre (Fig. 43). Unlike other cells, a muscle fibre has a large number of nuclei. If we examine a muscle fibre under the microscope, it is found to be a bundle of myofibrils. Each myofibril shows alternate dark and light zones or bands. The dark and light bands of different myofibrils in a

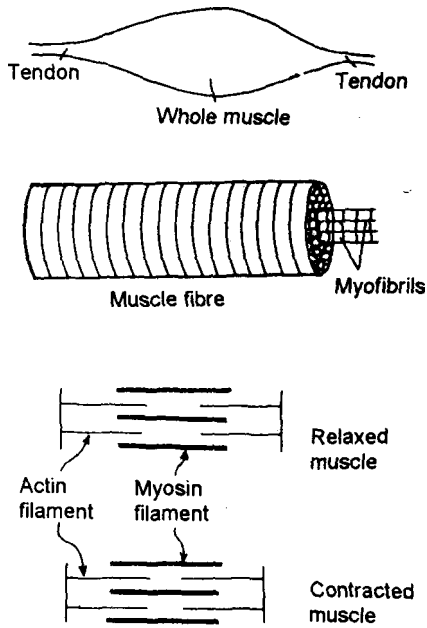

Fig.43: A muscle (*top*) is made up of a large number of muscle fibres. Each muscle fibre is made up of several myofibrils, which in turn have in them very neatly and regularly arranged myofilaments of two types—actin and myosin. Sliding in of actin filaments accompanies contraction.

muscle fibre are arranged in such an orderly fashion that a muscle fibre as a whole also appears to have alternate dark and light zones. This gives the muscle fibres an appearance of being striped or 'striated'. That is why skeletal muscles are also called 'striated muscles'. If we magnify a myofibril further, we can see in it two types of myofilaments arranged in a geometrical fashion. The two types of filaments are made up of the proteins, actin and myosin. Actin filaments are thin, and make up the light bands; myosin filaments are thick, and make up the dark bands. When a muscle contracts, the thin filaments slide in while the thick filaments stay where they are (Fig. 43). This is how the muscle as a whole gets shorter.

It was mentioned in passing earlier that voluntary muscles contract only when their nerve supply is activated. Each skeletal muscle is supplied by at least one nerve. Just as the muscle is made up of muscle fibres, the nerve is made up of nerve fibres. On entering a muscle, each nerve fibre branches out and supplies a few muscle fibres. The more the nerve fibres are activated, the larger will be the number of muscle fibres activated simultaneously. This is

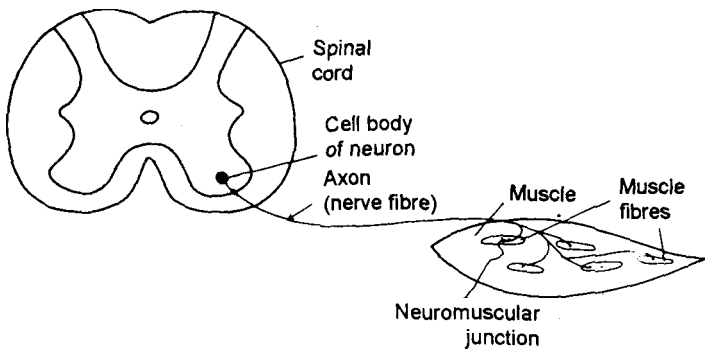

Fig.44: Muscles are supplied by nerve fibres originating from neurons, the cell bodies of which occupy a specific corner in the spinal cord. One nerve fibre generally supplies a large number of muscle fibres.

how the force of contraction is altered. The nerve fibres supplying a voluntary muscle are, in fact, the axons of nerve cells (neurons), the cell bodies of which occupy a small well-defined niche in the spinal cord (Fig. 44). This particular site of the spinal cord is damaged in polio, leading to paralysis of muscles. The activity of these cells of the spinal cord is further modulated by various regions of the brain, including the highest, viz. the cerebral cortex. Cerebral cortical control makes voluntary movements possible, and also imparts accuracy and delicacy to the movements.

The next question that arises is how the nerve fibres tell the muscle fibres to contract. The message is conveyed along the nerve fibre in the form of propagated electrical impulse. At the place where a nerve fibre meets a muscle fibre (neuromuscular junction), the nerve fibre expands and rests like a foot (Fig. 45). The expanded terminal

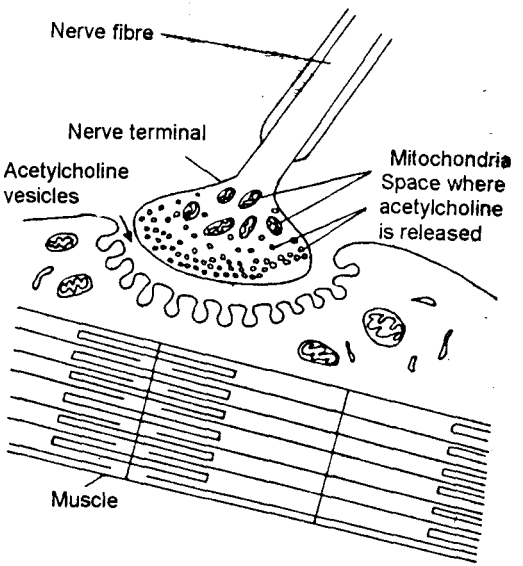

Fig.45: The nerve ending terminates very close to a muscle fibre in the form of a swollen structure. Neuromuscular junction is a specialised region for efficient transmission of nerve impulses to the muscle fibre.

contains a large number of tiny balloon-like structures (called 'vesicles') containing acetylcholine. When electrical impulses travelling along the nerve fibre reach the terminal, acetylcholine is released in the narrow space between the nerve and the muscle. Acetylcholine induces electrical activity in the muscle, which, through a series of events, leads to sliding in of thin filaments, and consequently, muscular contraction. From the above account, and some earlier chapters, it is evident that the activity of all excitable tissues, i.e. nerves and muscles, is associated with electrical activity. Just as the record of electrical activity of the heart is called an 'electro-cardiogram' (ECG), the record of electrical activity of muscles is called an 'electromyogram' (EMG). EMG is useful for diagnosing and tracing the progress of several disorders of muscles.

Excessive use of a skeletal muscle makes it stronger and bulkier, which is due to an increase in the size of the individual muscle fibres. On the other hand, not using a muscle induces disuse atrophy. Physical exercise not only makes muscles stronger but also brings about favourable changes in circulatory and respiratory systems so that a trained person can undertake physical exertion with greater ease. Prolonged and continuous use of muscles for such activities as walking or cycling makes the muscles and their tendons painful. But they recover after a period of relaxation.

Our 'moving story', or story of movement, would not be complete unless we talk about the joints which are, literally, at the centre of every movement. Joints are an engineering marvel—serveral mechanical devices work in a manner similar to joints but perhaps none is as good. Some joints, such as the shoulder or the hip joint, are of the ball and socket variety; some others, such as the elbow and knee, are of the hinge variety. Joints are not mere approximation of two bones—they come complete with appropriate cushions (cartilages) and lubricant (synovial fluid) (Fig. 46). As a result, they work so silently for decades that we

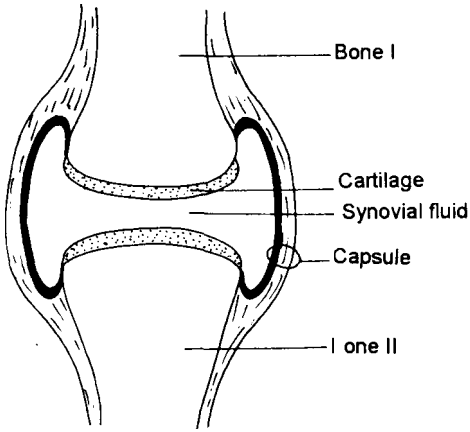

Fig.46: The structure of a typical joint. The two bones involved are separated by cushion-like cartilages which act as shock absorbers, and the synovial cavity is filled with a fluid which acts as a lubricant.

take them for granted. But sooner or later, they do complain. It is rare to find an adult who has never had pain in the joints. Some simple principles can help us prevent and ameliorate common forms of joint pain.

The commonest joint pain in India is due to osteoarthritis. It essentially results from the effects of wear and tear, but the predisposition to get it seems to be inherited. Although one cannot choose one's parents, it is possible to reduce wear and tear. An overweight person imposes a heavy burden on his joints. That is the reason for osteoarthritis being the commonest in weight-bearing joints, such as the knee. That is also why overweight persons are more prone to get osteoarthritis, and patients having it are advised to lose weight. Secondly, muscle contraction around a joint protects it from part of the weight acting on it. That is why patients are advised exercises for strengthening of muscles, and persons with strong muscles are unlikely to get joint pains. Osteoarthritis is a mild, non-crippling disease. But there are several other types of joint diseases, in which not only there is pain, but also redness and

swelling of the joints. One of the commonest of these, rheumatoid arthritis, can eventually lead to severe disability. However, in view of the large variety of joint diseases, instead of getting alarmed, it is better to seek proper medical advice. Because of the chronic and intractable nature of joint diseases, they provide a fertile field for quacks and charlatans. But visiting them often consumes time and money without giving commensurate benefit, and may sometimes do more harm than good.

One series of joints deserving special mention is the back. Backache is one of the commonest symptoms after middle age, and is largely preventable if the underlying physiology is understood. The backbone is made up of a row of ring-like bones, called 'vertebrae'. If a man lifts a heavy weight, which may well be half his own weight, the pressure on the vertebrae can exceed what the soft cushions interposed between successive vertebrae can stand. The reason why a normal individual is able to lift such weights is that while doing so there is a reflex contraction of muscles of the rib cage, belly and back. This converts the chest and abdomen, including the backbone, into a rigid cylinder. With an increase in area sharing the load, the stress on the backbone drops by 30-50 per cent, thereby making it easily bearable. The impact of area on pressure can be understood from a simple example. If a person stands on sand, his feet sink in, but if the same person lies down on the same sand, he hardly makes a dent. The reason is that his body weight exerts a much greater pressure on sand in the standing position than in the lying down position because the area in contact with the sand is much larger in the lying down position.

The key to a healthy back, therefore, is to have such healthy abdominal and back muscles that the chest and abdomen behave like a rigid cylinder, sharing as one unit the weight imposed on the back.

Based largely on the principles discussed above, following are a few rules for preventing problems with

the back:

- Keep good posture.
- Avoid shoes with high heels.
- Avoid unaccustomed weight-lifting and sudden movements of the back.
- Lift weights the correct way (Fig. 47).
- Do not try to lift, push or pull when off the balance, or while turning or twisting. One should arrange the situation in such a way that one is standing on a secure foundation, facing the direction of movement before picking up a load.
- Keep abdominal and back muscles in good shape by appropriate exercises—swimming is one of the best; walking or running upstairs or uphill are also good for the trunk muscles.

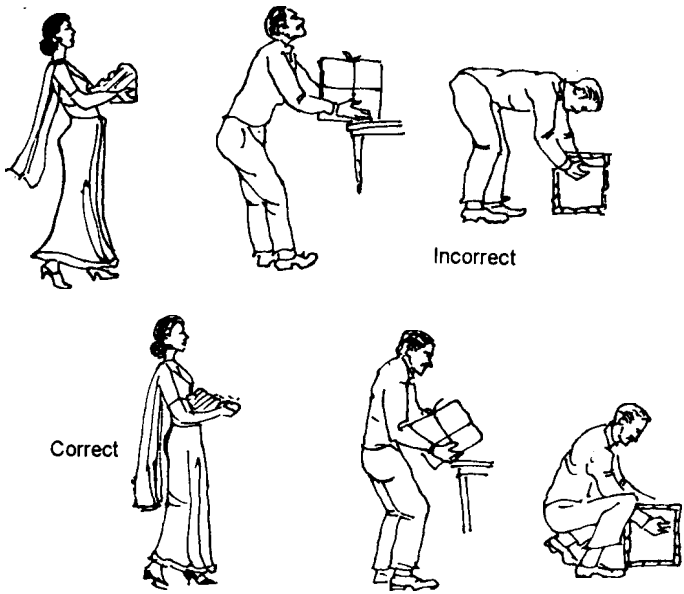

Fig.47: The incorrect and correct ways of lifting weights. The incorrect ways are needlessly cruel to the back. (Adapted, with permission from Astrand, P.O. and Rodahl, K.: *Textbook of Work Physiology*, 1970, Fig. 8-11. *Courtesy*: McGraw Hill Book Co., New York, USA.)

Muscles and joints do not contribute to life processes the way lungs or kidneys do. But their contribution to survival is indispensable. No animal can survive if it cannot move about to find its food; even human societies are able to support only a small number of paralysed individuals rather imperfectly. Nature, in its supreme wisdom, has therefore given muscles about half a man's body weight.

13

HEARING AND NOISE

Deafness is often not considered a serious handicap. A blind or a lame man often attracts more sympathy and understanding than a deaf person. This is probably because his misery is not associated with obvious disfigurement. If a child is born deaf, he grows dumb as well (unless treated) because in order to learn speaking, he needs to hear. He is thus condemned to a life without proper communication with his fellow beings. The misery of a person who becomes deaf after having lived normally for a few years is no less, specially if the malady comes suddenly. For effective communication, one needs to speak as well as listen. Not being able to listen invites embarrassment, misunderstanding, and sometimes ridicule. This tends to make the victim withdraw into his own shell. He gets buried into a pit of loneliness with only nostalgic memories of the past to cherish. The famous composer, Beethoven, became deaf at the age of twenty-eight. No doubt, he composed some of his best pieces only after becoming deaf, but, it is a pity that he couldn't hear them himself. He wrote, "O my fellow men, who consider me. . . unfriendly, peevish or even misanthropic, how greatly do you wrong me. For you do not know the secret reason why I appear to you to be so. Ever since my childhood, my heart and soul have been imbued with tender feelings of goodwill, and I have always been ready to perform even great actions. . . If at times I decided just to ignore my infirmity, alas, how cruelly was I then driven back by the intensified sad experience of my poor

hearing." There are many preventable causes of deafness, e.g. overconsumption of aspirin, lack of iodine in the diet, and some infectious disease of the middle ear. Now we can add to the list a very important cause which is purely man made, i.e. noise. In this context, noise means any sound that is physiologically harmful even if the listener finds it pleasant— 'rock' music— or useful, e.g. the sound of some machines.

How We Hear

For a proper understanding of how noise harms us, we should know something of how we hear (Fig. 48). The sound waves are funneled into the ear by the cup-like external ear which we can all see. The waves strike the

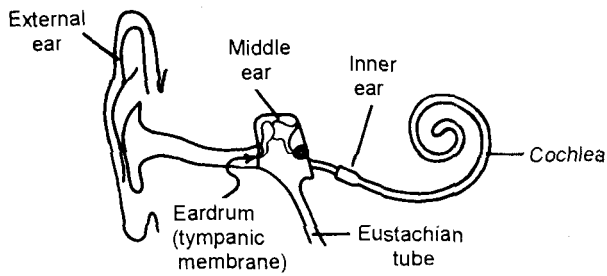

Fig.48: The external, middle and inner ear.

eardrum and throw it into vibration. The vibrations of the eardrum are communicated to a system of three minute bones, barely visible to the eye. The bones act like an efficient lever. The last of the bones fits like a piston into the inner ear. Because the area of the piston is only about one-twentieth the area of eardrum, the pressure (force per unit area) transmitted to the inner ear is about twenty times as much. This is an important service the tiny bones perform because the inner ear is filled with a watery fluid, and it takes much more pressure to produce vibrations in water than in air. The inner ear is snail shaped, and is in fact a long

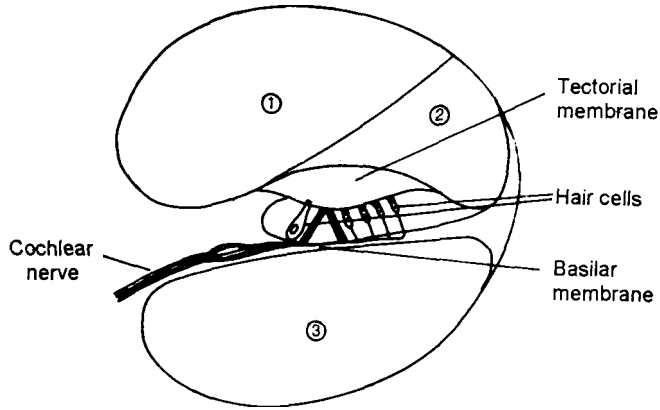

Fig.49: The inner ear, or cochlea, is a long coiled tube. If it is cut across at any point, it is seen to be divided into three compartments (1, 2 and 3). One of the partitions, the basilar membrane, bears the sensitive hair cells. The hair cells are in contact with the shelf-like tectorial membrane. The fibres of the nerve of hearing (cochlear nerve) originate as processes extending from the hair cells.

coiled tube. The tube is partitioned into compartments all along its length (Fig. 49). The major partition, called the 'basilar membrane', bears along its entire length, millions of neatly arranged cells which have small hair-like outgrowths. As the fluid in the cochlea vibrates, the basilar membrane and consequently the hair cells vibrate. Vibration of hair cells makes the hair rub against a shelf in the inner ear—the tectorial membrane. Rubbing of the hair results in transmission of a message to the brain which makes us aware of the sound. The stiffness and width of the basilar membrane is so graded along its length that different positions of it vibrate in response to sounds of different pitch. That is how we can make out the pitch of a sound.

How Noise causes Deafness

A machine gets damaged if it is over-used, misused or abused. This holds good for the ear as well. Depending

upon the nature of the sound, the external, middle or inner ear can get damaged by noise. Any part of the ear may get damaged by a brief explosive noise like the one produced by fireworks, bomb explosions, or shooting. Here the effect of noise gets compounded by the effect of the blast which can rupture the eardrum, or dislocate the tiny bones of the middle ear. The hair cells of the inner ear can also get damaged by a short explosive noise. In addition, prolonged, non-explosive noises cause subtle damage to the inner ear or neural pathways. The damage is not always visible, even under the microscope. Noises which cause slow and progressive hearing loss include vehicular noise, aircraft noise, noise from fans, air-conditioners and generators, noise from radio, television and gramophone records, and noises from factories, especially those involving riveting, chipping, boiler-making and weaving. That long-term exposure to noise causing deafness has been proved by the high incidence of early deafness in those engaged in occupations which involve exposure to noise. Further, the 'normal' partial deafness of old age has been found to be more severe and of earlier onset in people living in modern industrialised societies than in primitive tribals living away from factories and automobiles. However, the degree of susceptibility to the effects of noise differs widely from one individual to another.

Other Effects of Noise

Effects of noise on functions other than hearing are mainly psychological. The susceptibility to these effects varies even more widely from one individual to another than is the case with effects on hearing. Some people find it difficult to sleep in noise, some don't care, while others need some 'noise' (e.g. lullaby) to fall asleep. The effect of noise depends also upon the type of sound. For instance, the loud sound of aircraft or the constant ticking of the clock may not interfere with sleep, but the feeble cry of her infant will at once wake up a mother. During daytime also,

sounds produce varying degrees of resentment among individuals. Many of the people staying close to airports or railway stations indeed believe that noise has made their life miserable. Among workers, it has been found that noise impairs performance and many types of jobs. This may be partly because of the interference with communication caused by the noise. Usually it is found that the rate of working is not reduced but there is an increase in the errors committed.

Overcoming the Ill-effects of Noise

The ill-effects of noise can be minimised at many stages. Since prevention is better than cure, the ideal course would be to silence the source of noise itself. The ideal is not always possible or practicable. Some examples of reducing noise at the source are the silencers fitted to automobiles, oiling of machines, or fitting rubber pads to parts which have to strike each other. When sound cannot be reduced at source, it can be kept at a distance. That is one reason why airports are located at a distance from the centre of the city. However, some houses and hotels, of necessity, have to be close to airports or busy roads. In such cases, a little attention to construction can often minimise noise considerably. The silence which you can provide through advanced techniques of construction can be judged from the way a reporter described a new hotel near the London Airport in *The Observer* (London) of 15 March, 1964: "That this was effective was proved to me by the eerie sight of a soundless Boeing 707 floating past a double glazed bedroom window, while the hotel was full of noisy visitors, none of whom I could hear."

In some industries where exposure to noise is inevitable, the number of persons exposed and the duration for which they are exposed can be reduced to a minimum. Further, during the exposure, ear protection should be used.

At least as important as providing protective devices is

the education of workers about the value of ear protection through lectures, demonstrations and films. This is very important because it has been found that even when protective devices are provided, the workers just keep them aside. They find it rather 'funny' to use them and often cannot see the harm they do themselves because of the slowness with which the ears go deaf. Last, but not least, the workers exposed to noise should be periodically examined to pick out those who are specially vulnerable so that they can be shifted to alternative jobs. Other workers should also be offered alternative jobs as soon as their hearing starts declining.

The expansion of industry and proliferation of automated transport has given rise to considerable noise, which often reaches dangerous levels. Discotheques also often cross the safe limits of noise, particularly when they play live rather than recorded music. The noise can be reduced significantly if we become conscious of its dangers.

14

SEEING AND BELIEVING

It is not difficult for even a person blessed with normal vision to appreciate the value of vision. In terms of clarity of vision, as well as in terms of variety of shapes and range of colours perceived, man fares better than most animals. The excellence of the sense of sight has tempted man to rely almost exclusively on it for pursuit of food and safety. This is in contrast to animals who depend a lot more on smell and hearing for these activities. Perhaps through disuse, man has suffered a blunting of other senses, particularly that of smell. It is difficult for a man with his eyes closed to find his way around, and to steer himself safely on the road for even a short distance. In addition, much of our knowledge about the world comes through our eyes. Apart from these necessities, vision is also the means by which we can enjoy and appreciate beauty, colour and brightness of the world.

The process of seeing may be divided into a relatively simple physical process comparable to the formation of image in a photographic camera, and a complex neural process resulting in conscious perception of what is seen. The former takes place in the eyes, and the latter in the brain. The optic nerves provide the link between the two.

The visible part of the eye is only a small part of the eye. Each eye is almost spherical in shape, and is, therefore, called the 'eyeball' (Fig. 50). The ball-shape is maintained by two fluids—aqueous and vitreous humor. The outermost layer of the eyeball is the tough, opaque, white 'sclera'. It, however, becomes delicate and transparent

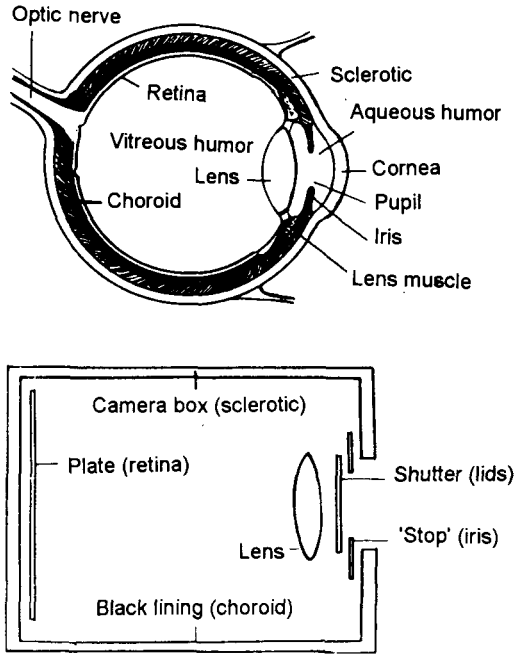

Fig.50: Diagrammatic representation of the structure of the eyeball. The eye has been compared with a camera in the lower diagram. (Reprinted with permission from Moon, T.J., Otto, J.H. and Towle, A.: *Modern Biology*, 1963, Fig. 40-9, p. 511. *Courtesy*: Holt, Rinehart and Winston, Inc., New York, USA.)

over a circular patch in front of the eyeball, where it is called the 'cornea'. Transparency of the cornea is essential for light to enter the eyeball, and that is a prerequisite for seeing anything at all. Loss of transparency of cornea is one of the common causes of blindness. This may result from an accidental injury to the cornea, or from a variety of diseases. One of these diseases, smallpox, has happily been eradicated from the world. Another common disease of the eye, trachoma, if ignored, ultimately leads to corneal opacities in its late stages. The most unfortunate preventable cause of blindness is deficiency of vitamin A. The deficiency can be prevented if the consumption of just 50

g of green leafy vegetables can be ensured every day. If corneal opacity is the only defect in the eye, vision can be restored by an operation in which the opaque cornea is replaced by a transparent cornea taken from a donor's eyeball. Fortunately most of us, even after using our eyes for decades, die with healthy corneas, and therefore have, even after death, the opportunity of giving a priceless gift to an unknown needy person.

The layer of the eyeball next to the sclera and cornea is 'choroid'. Choroid is richly supplied with blood and contains a coloured substance. Just behind the cornea, the choroid is called the 'iris'. The colour of the iris determines the colour of the eyes—it may be black or dark brown, or it may be blue or grey. In a blue or grey iris, there is a distinct pattern of rays, rings and spots. This pattern is highly individualistic, and has been suggested as an alternative to finger-prints for identification.

The iris is deficient in the centre, leaving a gap of alterable dimensions called the 'pupil'. The pupil is the space that admits light. Its diameter in man may range from 1.5-8 mm depending, usually, on the intensity of light. In bright light, it narrows down, reducing the amount of light that may be admitted. In dim light, it is beneficial to admit as much light as possible, hence the pupil opens up. Besides intensity of light, the distance of the object looked at also affects pupil size. When a near object is being examined, the pupil shrinks to a smaller size.

The innermost layer of the eyeball is the 'retina'. It is the light-sensitive layer comparable to the photographic film. Its sensitivity to light is due to the presence of elongated receptors of two types, called 'rods' and 'cones', names which roughly indicate their shapes.

The only important structure of the eyeball, that has yet not been mentioned, is the 'lens'. It is transparent, has a bulge in the centre, and is elastic in consistency. Its elasticity, and the way it is suspended in the eyeball, makes it possible for the lens to alter the thickness of the central bulge.

The lens often gets opaque in elderly individuals. The change is gradual, and its exact causes are still unknown. The resulting condition is called 'cataract'. Not enough is known about the causes of cataract to be able to suggest any preventive measures. When cataract has advanced to such an extent as to handicap the individual in carrying out his profession or daily routine, it can be treated by an operation in which the lens is removed. After removal of the lens, the patient is usually given glasses which try to make up for the lost lens. Alternatively, an artificial lens, made of a plastic material, may be implanted during the operation to replace the lost lens. One need not wait for the cataract to mature fully before operating upon it, as has been the traditional concept. With the present-day surgical techniques, it is not necessary.

The rays of light enter the eye through the cornea, traverse the lens, and strike the retina. The curvature of the cornea and the fact that it has air on the outside, and fluid towards the inside, ensure that rays of light bend as shown in Fig. 51, as they pass through the eyeball. As seen in the diagram, the image formed on the retina is upside down.

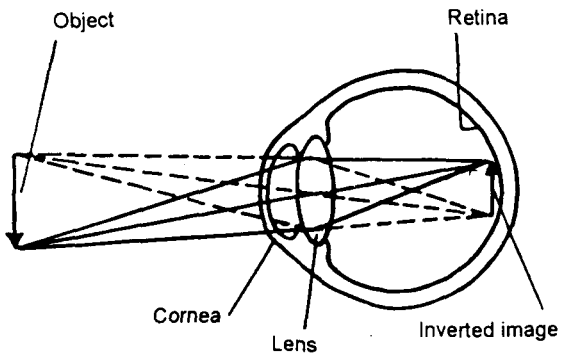

Fig.51: The formation of image in the eye. (Reprinted with permission from Moon, T.J., Otto, J.H. and Towle, A.: *Modern Biology*, 1963, Fig. 40-8, p.510. *Courtesy*: Holt, Rinehart and Winston, Inc., New York, USA.)

The perceptive processes in the brain reinvert the image to make it the right way up. The dimensions of the eyeball and lens have to be within a very narrow range to ensure sharpness of the image. Therefore, even relatively minor alterations can result in blurred vision. These defects are called errors of refraction and are the *commonest* disorders of vision. There are three major categories of errors of refraction.

Myopia (Short-sightedness)

This is usually the defect in young persons who need glasses. They find it difficult to see distant objects clearly, although they can read a book provided they keep it close

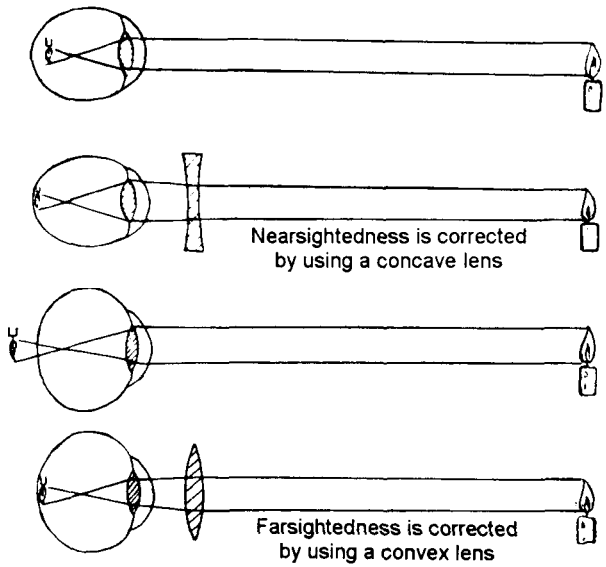

Fig.52: Common errors of refraction and their correction. In near-sightedness (myopia) the image is formed in front of the retina, and can be made to form exactly on the retina by using a concave lens. In far-sightedness (hypermetropia), the image is formed behind the retina (if that were possible), and a sharp image can be made to form on the retina by using a convex lens. (Reprinted with permission from Moon, T.J., Otto, J.H. and Towle, A.: *Modern Biology*, 1963, Fig. 40-10, p.512. *Courtesy*: Holt, Rinehart and Winston, Inc., New York, USA.)

enough to the eye. The defect is often discovered when the child experiences difficulty in reading the blackboard at school.

From the point of view of optics, myopia is the result of refraction that is a bit too strong. Correspondingly, correction involves use of concave lenses (Fig. 52). Such lenses are spherical, and their power is denoted by a negative (minus) sign. They are usually for constant use. Myopic children should get frequent (at least once a year) check-ups because so long as they are growing, their eyes also grow and the dimensions of their eyeball are liable to change. Hence the prescription for their glasses also changes, usually for the worse. However, except in the case of very high myopia (requiring for correction a lens stronger than -6), there is nothing to worry about. It is rare for the prescription to change after twenty-five years of age. However, the halt is temporary, and around forty years of age, a change is needed again, but for the better. The improvement is illusory since like the rest of the population, myopes also start getting presbyopic around that age. A mixture of pre-existing myopia and developing presbyopia produces an illusion of improvement, although what it might ultimately lead to is bifocal lenses—a separate lens for each defect.

Hypermetropia (Long-sightedness)

In this defect, the person is able to see distance objects relatively clearly, but finds it difficult to see the details of near objects. Therefore, he finds reading a strain. Straining while reading might also bring on a headache. In this condition, the power of the lens is insufficient to focus near objects clearly on the retina. A functionally similar defect called 'presbyopia', develops almost universally with age, usually after forty. Presbyopia is due to the aging process which hardens the lens. Thus the lens fails to get thicker (stronger) during reading. Correction of both hypermetropia and presbyopia is by convex lenses, the power of

which is denoted by a positive (plus) sign.

Astigmatism

In this defect, the horizonatal lines may be seen more clearly than the vertical, or vice versa. Astigmatism may be present alone, or in association with other defects of vision. It is usually a minor defect that does not cause much visual difficulty, but is frequently the cause of headaches. In case of an intractable headache which is present most of the time, it is advisable to get an eye check-up. Paradoxically, it is usually small errors rather than big errors of refraction that cause headaches.

The most familiar device by which eyes are tested for errors of refraction is the Snellen's chart. In this chart the topmost letter can be read by a person with normal vision from a maximum distance of 60 metres, and the last but one line from 6 metres; the lines between them can be read from intermediate distances. The patient is seated at a distance of 6 metres from the chart, and asked to read it from top downwards with one eye at a time. His vision is designated by a fraction, the numerator of which is usually 6, indicating that he is 6 metres away from the chart. The denominator is the maximum distance from which a person with normal vision should be able to read the last line read by the patient. For instance, if the last line that the patient can read from 6 metres is the one that can be read normally from upto 24 metres, the patient's vision is designated as 6/24. It must be noted, however, that even an individual who can read the last line might have a significant error of refraction and require glasses.

Binocular Vision and Squint

Nature has given us two eyes. Many other organs, e.g. lungs and kidneys, are also in pairs, which provides a reserve organ in case one of them is diseased. But in case of eyes, the significance is wider than that. The presence of two eyes broadens our field of vision, and improves

perception of depth. Vision based on two eyes is spoken of as 'binocular vision'.

It is a common observation that both eyes move simultaneously and to the same extent when one looks to one side, up or down, without turning the neck. The movement of eyes is produced by muscles attached to the outside of the eyeball. The other end of these muscles is attached to the bony hollow in which the eyeballs are placed. Co-ordinated function of these muscles is essential for simultaneous perception of the same object by both eyes. If the co-ordination is impaired, the result may be obvious squint. Squint is not just a cosmetic disfigurement, but may result in only one of the eyes being used for vision. Prolonged disuse of one eye may impair its vision. If not treated in time, the visual loss may be permanent. Such a loss of vision may also result from refusal to use glasses, specially when advised in childhood, particularly when the degree of refractive error in the two eyes is markedly different. Squint and subsequent visual loss may be prevented by getting every child's eyes examined before school age. If, however, the defect is detected, treatment should be sought at the earliest.

Retinal Function

So far we have more or less taken for granted the formation of image on the retina. We have already seen that light rays striking the retina stimulate light-sensitive receptors called 'rods' and 'cones'. Rods can perceive even dim light but cannot perceive a colour and do not give a very sharp image. On the other hand, cones require bright light to be stimulated, respond differently to different colours, and give a very sharp image. The central portion of the retina has a high density of light receptors, and they are mostly cones, while the peripheral part of the retina has receptors rather sparsely distributed and they are mostly rods. That is why objects right in front of the eye are seen clearly, while objects lying on one side or a little behind are

perceived as a haze. By the same token, in bright light objects are seen clearly and in their true colours, while in dim light, vision is indistinct and everything puts on a greyish or bluish hue.

The sensitivity of rods and cones to light is due to their containing a coloured substance called 'pigment'. The visual pigment of rods is different from that of cones; it is further thought (with some evidence) that cones have three different types of pigments corresponding to three primary colours—green, blue and red. Each of these three pigments is maximally sensitive to only one primary colour. In other words, the colour that we perceive depends on the ratio in which the three types of cones are stimulated. That is quite analogous to making various shades by mixing primary colours in different ratios. Deficiency or absence of one or more type of cone pigments gives rise to various forms of colour weakness or colour blindness. Like haemophilia (Chapter 3), colour blindness is also a sex-linked disease which affects only males. Surveys have revealed that about 8 per cent of males are colour blind. Colour blindness is usually partial, and is ordinarily not a serious handicap. In fact, the more common milder forms are little more than an occasional social embarrassment. However, colour blindness precludes employment of the affiliated persons in some occupations, like flying or engine driving where accurate perception of colour is of crucial importance.

Chemically, all visual pigments are a combination of a derivative of vitamin A and a protein. That explains to some extent why one of the earliest symptoms of vitamin A deficiency is delay in dark adaptation. It is common experience that on entering a dark room, such as a cinema hall, for the first few seconds, nothing is visible. But gradually the visibility improves, and everything appears reasonably clear. This change takes much longer and is less complete in vitamin A deficiency. Once the image formed on the retina has been translated into a pattern of stimulation

of rods and cones, the information is conveyed to the brain by means of nerve fibres. The first set of nerve fibres orginates in the rods and cones themselves. These nerve fibres are carried in the optic nerves. After a series of relays in neurons, most of the nerve fibres ultimately convey their information to the hind part of cerebral cortex called the 'visual cortex'. Some crude perception of objects seen may be possible at lower levels, but detailed perception with its attendant interpretation and discrimination takes place only in the cerebral cortex. Quite a few of the optic fibres do not reach the cerebral cortex. They get diverted at lower levels of the brain to form a part of reflex arcs. These reflex arcs are responsible for the visual reflexes. One example of visual reflexes is the involuntary blinking that takes place when a fast approaching object is about to strike the eye; the protective value of the reflex is obvious. Another example is the change in the shape of the lens when we suddenly shift our attention from a distant object to a near one or vice versa. This reflex is called the 'accommodation reflex', since it 'accommodates' the eyes to a change in the location of the target of its attention.

That was a short story of the visual process. The eye is, in a way, part of the brain that is lodged outside the cranial cavity. To the physician, therefore, the blood vessels of the retina (which can be seen with an ophthalmoscope) provide a conveniently placed view of the state of blood vessels in the brain. The optic nerves provide the physical link between the eyes and the brain. What the eyes 'see' does not make sense till the signals sent by the optic nerves have been processed by the perceptive mechanisms of the visual cortex. We are still at a very elementary stage in our understanding of these mechanisms. What one perceives and appreciates on seeing objects of different forms or shapes partly depends on training, and has a good deal of subjective element in it. Hence, the adage that beauty lies in the eyes of the beholder.

15

SEX AND THE CYCLE OF LIFE

Sex is all things to all men, from the most abominable instinct to a source of utmost pleasure. The biological reason for sex lies in the necessity for preservation of the species, or still more broadly, the perpetuation of life on our planet. So strongly has this necessity been felt by Nature that it has immensely overloaded us with the sexual desire. While animals satisfy the sex urge in the same way as they satisfy hunger and thirst, man has built around sex a network of social, ethical, religious and legal aspects. At its best, sex stimulates creativity. However, the animal in man often overrules his head, making sex responsible for considerable crime and disorder. Although sex involves all these varied angles and more, the present discussion will be confined to the biological aspects of sex.

The Beginning of Life

Let us begin from the beginning. Life begins in the mother's womb as a result of the union of two microscopic specks of life—one from the mother, and one from the father—each called a 'gamete'.

All animals (and plants), except some very simple ones, are made up of a large number of microscopic units called cells (Chapter 2). The cells have a rounded structure called the 'nucleus', which contains a large number of paired thread-like structures, called 'chromosomes'. In human beings, all cells of the body have twenty-three pairs of chromosomes (*see* Fig. 8). Chromosomes carry the determinants of our bodily features, the 'genes'. Twenty-two pairs

of chromosomes in human cells, called 'autosomes', are alike in men and women. They determine features like the colour of the skin, hair or the eyes, the shape of nose or hands, and to some extent, even the personality make-up. The twenty-third pair, called the pair of 'sex chromosomes', consists of two similar members in women, and is designated XX. In men, the two members of the twenty-third pair are dissimilar, and it is, therefore, designated XY. Like all parts of the body, *sex organs* also have cells containing twenty-three pairs of chromosomes. However, within these organs, some cells divide in such a way that they contain only one member of each pair of chromosomes. These cells with only half the quota of chromosomes are called 'gametes'. Thus the female gamete contains twenty-two autosomes and an X chromosome. Male gametes are of two types: one containing an X, and another a Y chromosome, besides, of course, the twenty-two autosomes.

The male gamete, called 'sperm', is formed in the testes (Fig 53 & 54). The smallest of all human cells, it measures about 0.008 mm. It has a tiny oval head and a whip-like tail about nine times as long.

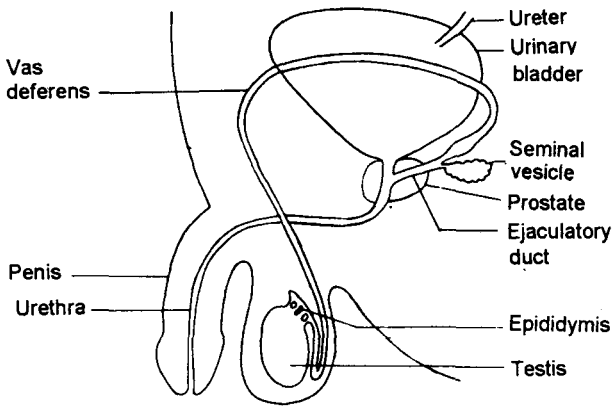

Fig.53: A diagrammatic representation of the male reproductive system. The connection with the urinary tract is obvious.

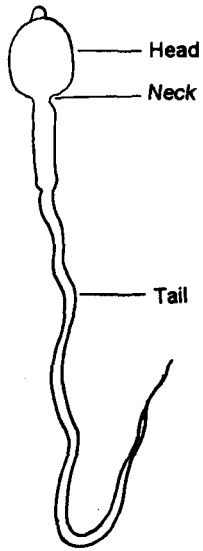

Fig.54: A sperm, the product of the male reproductive system, highly magnified.

It seems to be charged with an unimaginable store of energy, which enables it to swim its way to the ovum. Keeping the sperm's size in view, its 12 cm journey up to the ovum is the equivalent of a man's 5-mile swim upstream. The production of sperm is on a much more lavish scale than that of ova. About 5 hundred million sperms are deposited at a time so that at least one is likely to find the ovum, if an ovum happens to be available at the moment.

The female gamete is formed in the ovaries (Fig. 55), and is called the 'ovum' or egg cell. It is the largest of human cells, and is yet barely visible to the eye, being only 0.13 mm in diameter and 0.000004 g in weight. Usually one mature ovum is shed from the ovary every month during the reproductive age of a woman, which works out to about 400 ova in a life-time. Only a few of these unite with the male gamete.

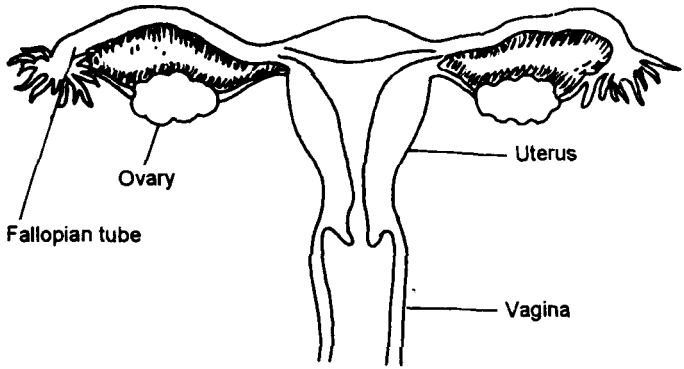

Fig.55: Diagrammatic representation of the female reproductive system.

The Menstrual Cycle

The periodic shedding of the ova by the ovaries is a part of a cycle generated by cyclic fluctuations in sex hormones, and in which the uterus (womb) also participates. Immediately after the ovum is shed, the uterus starts getting thicker, glandular and more richly supplied with blood. This preparation ensures adequate nourishment and a hospitable environment for the growing embryo in case the ovum is fertilised. More often than not, however, the 'guest' does not arrive to receive the red carpet welcome. As if to express disappointment, the uterus sheds its inner lining together with a considerable quantity of blood about two weeks after the ovum was shed. The 'mourning' (menstruation) goes on for about four days. Then the uterus undergoes repair. About ten days later, another ovum is shed and like a never-tired host, the uterus starts preparing to receive it all over again (Fig. 56). The menstrual cycle goes on till the age of about fifty, when ovulution also comes to a halt. This 'change of life' is called 'menopause'. Menopause may be accompanied by troublesome flushing of the face and neck, and emotional disturbance. The most important treatment of menopausal

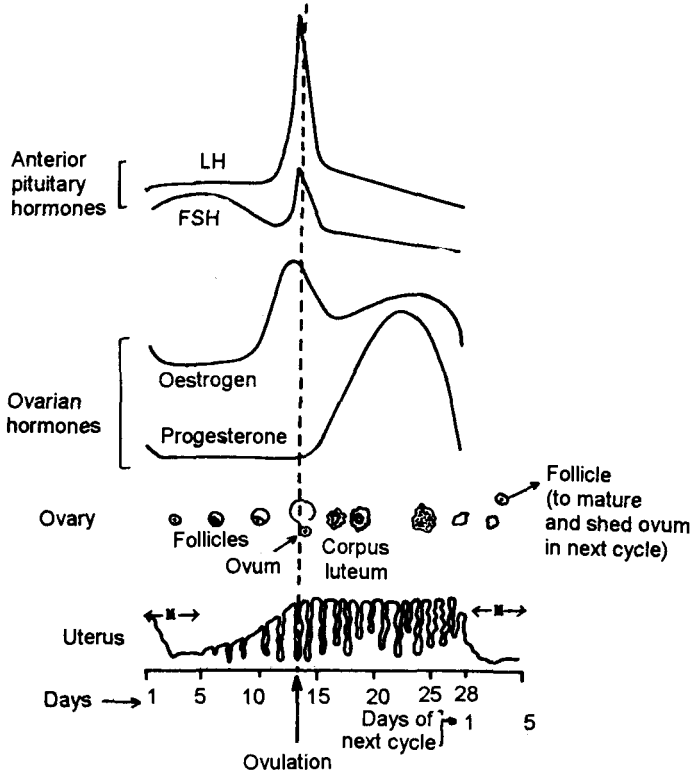

Fig.56: Hormonal changes during the menstrual cycle, and the accompanying changes in ovary and uterus. The ovum is shed around the middle of the cycle. *LH.* luteiniting hormone; *FSH.* follicle stimulating hormone; M. menstruation. (Adapted, with permission, from Luciano D.S., Vander, A.J. and Sherman, J.H.: *Human Function and Structure*, 1978, Fig. 21-13, p. 633. *Courtesy*: McGraw Hill Book Co., New York, USA.)

symptoms is the realisation on the part of the woman that it is normal, and that although she has lost her reproductive ability, she is still worth a lot. Her near and dear ones should also do their best to reassure her that she is still loved, wanted and cared for.

Fertilisation

The union of the ovum and sperm is known as 'fertilisation'.

The cell resulting from fertilisation is called the 'zygote'. The zygote contains the full quota of forty-six chromosomes. Since half the chromosomes have come from the mother and half from the father, the child which develops from the zygote has some features of both. This is how, through chromosomes, each one of us has at least some bit of characteristics from even the most primitive of our ancestors. The sex of the child to be born also gets determined right at fertilisation. The union of the ovum with an X-containing sperm produces an XX type of sex chromosome pattern in the zygote and therefore results in the development of a female child. On the other hand, if the ovum unites with a Y-containing sperm, the zygote contains the XY type of sex chromatin pattern and, therefore, results in the development of a male child.

Pregnancy

The zygote continues to move towards the uterus, but simultaneously also starts dividing. It first divides into two cells, the two cells divide into four, the four cells into eight, and so on. However, the daughter cells get progressively smaller so that by the time the product, now called the 'embryo', reaches the uterus, it is a compact mass of many cells, but the size of the whole mass is not really much bigger than that of the ovum or the zygote. The uterine wall is in a state of preparedness to receive the embryo. The embryo creates a shallow pit in the wall of uterus, and gets implanted there. Fertilisation also triggers appropriate change in the ovaries, so that hormones which had prepared the uterus to receive the embryo are not withdrawn. As a result, the uterus remains thick and well nourished, and there is no menstruation. For the woman, missing a menstrual period is the first indication that she is pregnant. In fact, she had become pregnant two weeks before she missed her period. Menstruation and ovulation stay suspended throughout pregnancy. During this period, a placenta is formed, which provides a link between the

maternal and foetal blood circulation. It brings oxygen and nourishment to the foetus, and takes away carbon dioxide and waste products from the foetus. Thus it performs the functions of lungs, intestines as well as kidneys for the foetus. The foetus develops by a twin process of cell division and differentiation. Cell division results in growth, and their differentiation into various shapes and functional units results in the formation of various parts of the body. Pregnancy continues for about nine months after which the baby is delivered. The expected date of delivery (EDD) is conventionally calculated from the date of the last menstrual period (LMP). Although fertilisation, or conception, takes place about two weeks after the LMP, LMP itself is used for the calculation since that is the date which is precisely known. The EDD is calculated by addition of nine months and seven days to the LMP. Thus if the LMP is 5th March, the EDD is 12th December. The actual date of delivery usually lies within one week of the EDD on either side. A woman who misses a period has nothing else to indicate that she is pregnant, for about a month. Therefore, she cannot be certain about the pregnancy: it could just be delayed periods. If she is curious to find out the true state of affairs, a 'pregnancy test' can be performed on her urine.

About a month after the missed period, some nausea and occasional vomiting in the mornings (morning sickness) is quite normal and almost universal. Morning sickness continues for at the most about two months, and then vanishes on its own. Besides morning sickness, the only other prominent symptom of early pregnancy is an increase in the frequency of passing urine. This symptom is due to the pressure exerted by the enlarging uterus on the urinary bladder. Paradoxically, the symptom disappears after about three months of pregnancy. The relief is provided by the fact that as pregnancy advances, the fattest part of the uterus keeps rising till it rises above the level of the urinary bladder, and is no longer able to press on it. After

the first three or four months of pregnancy, enlargement of the uterus makes its effects obvious on the appearance of the woman. If otherwise prone to constipation or piles, these disorders might be aggravated or precipitated during pregnancy.

During her first pregnancy, a woman receives multiple instructions regarding dietetic, gymnastic, psychological, and even sartorial discipline. On top of all this are her own imaginary hopes and fears. It is well to remember that pregnancy is a normal phenomenon and common sense can be relied upon for guidance. Some simple guidelines on the usual points of enquiry are given below:

- *Sleep:* A pregnant woman should spend about ten hours out of twenty-four in bed. If there is any difficulty in falling asleep, the doctor should be consulted before resorting to sleeping pills. Sleeping pills may affect the baby adversely.
- *Exercise:* Physical effort should be tailored to suit individual habits. Exertion short of fatigue is the ideal to be aimed at during pregnancy. Strenuous athletic activities should be avoided throughout pregnancy.
- *Diet:* Harbouring a growing baby makes it necessary for the pregnant woman to eat a little more than in the non-pregnant state. The quantitative increase should be of the order of about 10 per cent.

Qualitatively, the additional diet should be made up of simple wholesome foods, preferably a judicious mixture of cereals and pulses, some milk and milk products, and some green leafy vegetables. This attention to quality is also important because the growing baby has to form new living matter. If the mother does not eat well during pregnancy, both the mother and the baby suffer. The mother suffers because the baby, like a parasite, draws many of the nutrients from the mother, irrespective of their supply. If these nutrients are not being eaten in enough quantity, the mother would get malnourished. The baby suffers because some of the nutrients become available

only if the mother is eating enough of them.

Foods having strong odours, or those leaving an after-taste should be avoided as they may precipitate nausea and vomiting. In view of the tendency to nausea and vomiting, small but frequent meals might be helpful. Water should also be taken often, although a little at a time.

As would be noticed, no special food or fad diet is necessary; no major restrictions are advisable either. Simple wholesome foods might be continued with a small increase in quantity and minor adjustments.

- ***Bowel habits:*** Constipation is not uncommon during pregnancy. If necessary, some 'Isabgol' might be taken with milk to ensure the passage of soft stool reasonably frequently.
- ***Clothing:*** The dress should be comfortable. A woman who has borne a few children already might need a support for the belly.
- ***Breast care:*** Beyond usual cleanliness, no special care is necessary. However, if the nipples are retracted, regular manipulation for a few months before delivery might correct the disability by the time the baby comes.
- ***Sex during pregnancy:*** During the first few months of pregnancy, sex should be avoided to prevent the risk of an abortion. During the later months of pregnancy, sex should be avoided to prevent introducing disease-producing germs into the mother. During the middle period, there is no important reason for avoiding sex.
- ***Drugs:*** The growing embryo and foetus are much more susceptible to untoward effects of drugs than adults. Therefore, all drugs should be avoided during pregnancy. In any case, a pregnant mother should not take any drug without medical advice.

It is often felt that adequate supply of vitamins and minerals cannot be ensured through diet alone. Therefore, vitamin and mineral pills are routinely prescribed during pregnancy. These pills need not be considered drugs, and

should be taken in the prescribed quantity without any apprehension.

End of Pregnancy

The onset of labour is marked by frequent, regular and painful contractions of the uterus. The mechanisms that initiate labour are obscure but could possibly include mechanical pressure, change in the concentrations of oestrogen and progesterone, release of oxytocin from the posterior pituitary, and alteration in the sensitivity of the uterine muscle itself. As a wag once remarked, when the fruit is ripe, it falls. Once labour sets in, it becomes a self-perpetuating process. Uterine contractions initiate a chain of events that lead to more uterine contractions, and so on.

Labour is traditionally divided into three arbitrary stages. The *first stage* extends from the onset of labour pains to full dilatation of the cervix (the lower part of the uterus). At first, the pains are not severe, of about half minute duration; they occur irregularly at intervals of ten to thirty minutes. The onset of labour is soon followed by a 'show', i.e. discharge of a small quantity of blood stained secretion. As labour proceeds, the pains become more frequent and more severe. Towards the end of the first stage, each bout of pain lasts about a minute, and the pains come every three to five minutes. The duration of the first stage varies with the pregnancy. For the first pregnancy, it usually lasts from twelve to twenty-four hours, while for subsequent pregnancies it lasts six to eighteen hours. The end of the first stage may coincide with a gush of watery discharge, or the discharge may occur earlier in the first stage or later on in the second stage. The *second stage* of labour extends from full dilatation of the cervix to the delivery of the baby. During the second stage, the pains are more intense and more frequent. Besides, this stage is characterised by voluntary 'bearing-down' efforts on the part of the mother. The *third stage* of labour starts after the

delivery of the baby and extends till the placenta (after-birth) has been delivered.

Labour is a painful process. It is probably the only painful process in absence of disease. But it is a pain that is promptly and completely healed, quickly forgotten, and accompanied by a reward. The best that a woman can do is not to be tense and apprehensive about it, and to cooperate by making proper bearing-down efforts when asked to do so. Such a control, wilfully exercised, reduces the perception of pain. Besides, tension and apprehension prolong labour. Prolonged labour is distressful to the mother as well as the foetus, and also to those attending on them. It is well for the mother to remember that her own mother and millions of other women have gone through this experience before her successfully.

Lactation

The next natural event after delivery is looking after the baby. Nursing forms a very important component of maternal care after delivery, and serves as a partial continuation of the nine-month long organic bond between the mother and child. Physiologically, the very same pituitary hormone (oxytocin) which results in ejection of milk from the breast, also brings about a more complete reduction in the size of the uterus by contracting its muscles.

The same pituitary hormone (prolactin) which stimulates synthesis of milk in the breasts also suppresses shedding of ova in the ovary, delaying the birth of the next child, thereby providing a natural spacing mechanism.

Technological progress, has, however, disturbed the natural follow-up of pregnancy. This has not been an unmixed blessing. The major drawbacks of cow's or powdered milk are:

- These feeds being expensive, many families that take to them cannot provide adequate quantities to their children.
- Poor families living in tropical climates cannot observe

hygiene that should accompany bottle-feeding.

- Recent work has revealed numerous biochemical differences between human breast milk and other milk. The extent of differences is so wide that copying human milk may well be given up as a hopeless and frustrating exercise.

Therefore, there is now a consensus that breast feeding is the most convenient, economical, hygienic and satisfactory method of feeding infants. If the mother embarks on breast feeding with confidence, generally there is enough milk to meet all requirements of the baby for the first six months of life. Thereafter, some supplements might be necessary.

Although it can now be stated on a more scientific footing than ever before that breast milk is the best, one should keep in mind that babies have been successfully fed with the bottle. Therefore, if there is a compelling reason for the mother's inability to breast feed the baby, she need neither feel guilty, nor fear that her baby is doomed to a bleak future.

The Next Generation

The child, after birth, appears to be sexually dormant for a few years. Though Freud has suggested sexuality even in infants, the sexual characteristics, as commonly understood, appear in children only at puberty, which appears at about twelve to fourteen years in girls, and about two years later in boys. It has a tendency to appear at an earlier age in Western countries. The causes in terms of heredity, better nutrition, or late nights are not yet well understood.

At puberty, there is a sudden spurt of growth accompanied by enlargement of breasts, appearance of pubic and axillary hair, and onset of menstruation in girls; and appearance of pubic hair, beard and moustaches, change in voice, and nocturnal emissions in boys. At puberty, the child is overwhelmed by sudden changes in the body and needs support and guidance to [illegible] changes as

Written lucidly, this book provides correct knowledge to a layman about the complex human organism. The functions of different parts of the body have been explained with special reference to the deviations in normal function which we call disease.

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